IDOE

RNATIONAL DECADE OF OCEAN EXPLORATION

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INTERNATIONAL DECADE OF OCEAN EXPLORATION

PROGRESS REPORT VOLUME 7
April 1977 to April 1978

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PREFACE

The International Decade of Ocean Exploration (IDOE) is a long-term, international, cooperative program to improve the use of the ocean and its resources for the benefit of mankind.

On March 8, 1968, the President of the United States proposed "an historic and unprecedented adventure—an International Decade of Ocean Exploration for the 1970's." In December 1968, the United Nations General Assembly endorsed "the concept of an international decade of ocean exploration to be undertaken within the framework of a long-term programme of research and exploration. . . ."

In late 1969, the Vice President of the United States, in his capacity as Chairman of the National Council on Marine Resources and Engineering Development, assigned responsibility for planning, managing, and funding the U.S. program to the National Science Foundation (NSF), and set forth the following goals:

• Preserve the ocean environment by accelerating scientific observations of the natural state of the ocean and its interactions with the coastal margin—to provide a basis for (a) assessing and predicting man-induced and natural modifications of the character of the oceans, (b) identifying damaging or irreversible effects of waste disposal at sea, and (c) comprehending the interaction of various levels of marine life to permit steps to prevent depletion or extinction of valuable species as a result of man's activities;

• Improve environmental forecasting to help reduce hazards to life and property and permit more efficient use of marine resources—by improving physical and mathematical models of the ocean and atmosphere to provide the basis for increased accuracy, timeliness, and geographic precision of environmental forecasts;

• Expand seabed assessment activities to permit better management—domestically and internationally—of marine mineral exploration and exploitation by acquiring needed knowledge of seabed topography, structure, physical and dynamic properties, and resource potential, and to assist industry in planning more detailed investigations;

• Develop an ocean monitoring system to facilitate prediction of oceanographic and atmospheric conditions—through design and development of oceanographic data buoys and other remote sensing platforms;

• Improve worldwide data exchange through modernizing and standardizing national and international marine data collection, processing, and distribution; and

• Accelerate Decade planning to increase opportunities for international sharing of responsibilities and costs for ocean exploration, and to assure better use of limited exploration capabilities.

Shortly after receiving the Vice-President's charge, the National Science Foundation set up the Office for the International Decade of Ocean Exploration (now International Decade of Ocean Exploration Section) and began to define the U.S. program. In the first year of IDOE's existence, three areas were chosen for priority attention: (1) environmental quality, (2) environmental forecasting, and (3) seabed assessment. In 1971, living resources was added as a fourth program area.

A key goal of IDOE has been to make sure that data from all projects will be available to future users. In pursuit of this objective, the IDOE Office of NSF contracted with the Environmental Data Service (now Environmental Data and Information Service) of the National Oceanic and Atmospheric Administration to manage the scientific data for IDOE. The agreement included publishing this series of reports.

Lauriston R. King, Acting Head
International Decade of
Ocean Exploration Section

INTRODUCTION

This report, the seventh in a series, provides the scientific community and other interested persons with information, data inventories, and lists of scientific reports derived from U.S. IDOE projects. The text is arranged according to the program areas established for IDOE. Details of subprograms are given under appropriate programs. Currently funded projects are listed. Bibliographies follow subprogram text.

Appendix A contains the Report of Observations/Samples Collected by Oceanographic Programs (ROSCOP), a summary of reported observations received during the period covered by this Report. All IDOE grant holders must submit ROSCOP reporting forms to NOAA Environmental Data and Information Service's National Oceanographic Data Center (NODC) upon completion of a data collection activity. The ROSCOP summaries in Appendix A follow the same program sequence as the text.

Two charts follow the appendices. The first shows ocean areas for which data and ROSCOP summaries have been received by NOAA's Environmental Data and Information Service (EDIS) during the period covered by this report. The second shows ocean areas for which data have been received by EDIS from January 1970 to April 1978. Each numbered area is about 1,100 by 1,100 km (600 by 600 nmi) and, although entirely shaded, may contain only one reported observation.

EDIS either has the data or papers described in this report in one of its center archives or can assist in obtaining them. Queries may be addressed to any of the following EDIS centers:

National Oceanographic Data Center (NODC)
National Oceanic and Atmospheric Administration
Washington, DC 20235
Tel: (202) 634-7234
IDOE Project Leader: S. O. Marcus, Jr.

Marine Geology and Geophysics Branch
National Geophysical and Solar-Terrestrial Data Center (NGSDC)
National Oceanic and Atmospheric Administration
Boulder, CO 80302
Tel: (303) 499-1000, ext. 6339
IDOE Project Leader: J. B. Grant

Environmental Science Information Center (ESIC)
National Oceanic and Atmospheric Administration
Rockville, MD 20852
Tel: (301) 443-8137
IDOE Project Leader: R. R. Freeman

National Climatic Center (NCC)
National Oceanic and Atmospheric Administration
Federal Building
Asheville, NC 28801
Tel: (704) 258-2850, ext. 765
IDOE Project Leader: R. Quayle

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HIGHLIGHTS OF PAST YEAR'S PROGRAM

As in most large scientific programs, IDOE projects in the past year were at various stages of their life cycles. New projects have begun, others have drawn to a close, and still others have started to report findings of both scientific and social significance.

The Environmental Quality Program's newest project, Pollutant Responses in Marine Animals (PRIMA), tackles the complex problem of identifying biological indicators that can be used to assess the health of the marine environment. Both scientists and policymakers are acutely aware that many potentially toxic compounds exist in the air, sea, and land. Yet, valid diagnostic and predictive tools to pinpoint the effects of these poisons on individuals or communities of organisms do not now exist.

PRIMA scientists will focus on the specific chemical and physical changes in marine organisms caused by polycyclic hydrocarbons and kindred halogenated compounds. To start, the scientists will standardize their experimental and analytical techniques, establish chemical and biological baseline values, and design the right dosage and exposure conditions. Once these preliminary efforts are completed, the scientists will conduct experiments aimed at isolating the effects of the pollutants on specific functions of a variety of organisms. Finally, field studies involving all the investigators will be conducted at a common site. Results from these studies should identify biological indicators and provide early warning about the existence of pollutant stress. Early warning should enable corrective actions before serious damage is done to marine populations.

Airborne materials are second in importance only to rivers for altering the chemistry of the oceans. A second Environmental Quality project, Sea-Air Exchange (SEAREX), has begun to report findings on the way chemicals reach the oceans through the air. SEAREX scientists are taking detailed measurements of airborne chemicals from remote island stations in the Pacific Ocean on Eniwetok and American Samoa. Both sites are sufficiently isolated from heavy industrial activity so that it will be possible to establish baseline levels that later can be used to assess the nature of atmospheric pollution.

Scientists from the Woods Hole Oceanographic Institution and other collaborators made an unexpected find during a diving expedition on the Galapagos Rift in the Pacific in March 1978. They found animal communities made up of fields of dandelionlike organisms (possibly soft coral or crinoids), clams up to 4 cm across, and about 10 other species clustered around hot water vents and apparently thriving 2,500 to 2,700 meters below the ocean's surface. It is suggested that the explanation for the abundant life observed near underwater springs at the site is only marginally related to the increased temperature, but rather lies in a well-known microbiological phenomenon that occurs wherever the water has a high hydrogen sulfide content. Although this phenomenon is well known in shallow water, this is the first known occurrence in the deep sea. At the Galapagos vents, the source of energy for the growth of organisms apparently emerges from the submarine springs in the form of hydrogen sulfide. This inorganic sulfur compound can be used by a certain group of bacteria as a source of energy used to turn carbon dioxide into organic carbon. The growth of sulfide-oxidizing bacteria produces the ideal food for filtering organisms, which may include large clams or smaller organisms on which clams feed.

Scientists in the Geochemical Ocean Sections Study (GEOSECS) have completed the final field work with a 4½-month voyage to the Indian Ocean.

The Indian Ocean provides an important link with the Pacific and Atlantic, and its study will increase understanding of the variety of mixing processes that take place between the oceans.

The survey covered the entire Indian Ocean with three north-south transects extending from India to the Antarctic continent. Sampling of the circumpolar deep water across its boundaries in the Indian Ocean was given high priority because of the importance of this water mass in the east-west exchange of heat and salt with the Atlantic and Pacific Oceans.

By analyzing over 20 chemical species in a single seawater sample, the scientists can determine the water masses' sources and rates of movement. The naturally occurring stable and radioactive chemicals, resulting from land runoff or atmospheric fallout, can be used to determine the dispersion rate of manmade pollutants. Also, natural tracers transferred by particulate matter will aid understanding of marine biochemistry and geochemistry. Use has also been made of the bomb-produced element tritium to provide, for the first time, details of the structure and movement of bottom water formed in the Antarctic.

Relationships between chemical and physical parameters that were found to be highly useful for predictive modeling in the Atlantic and Pacific Oceans will be further tested for the Indian Ocean. One of the important questions for climate assessment involves knowledge of the carbon-oxygen system and how well the oceans can absorb the products of fossil fuel combustion. Both shipboard and shorebased measurements from the GEOSECS project will contribute to this body of knowledge.

Another dimension to the ocean's role in climate, long-period, large-scale, air-sea interaction, continues to be a central problem in developing the scientific basis for improved forecasting. Scientists in the Environmental Forecasting Program's North Pacific Experiment (NORPAX) have turned their attention to the role played by equatorial conditions in influencing both fisheries and climate in the Pacific. Equatorial currents, for example, are responsible for generating unusual ocean conditions in the Eastern Pacific which, in turn, affect fishery yields. Changes in these equatorial currents appear to affect the atmosphere and hence weather and climate over North America.

Between November 1977 and February 1978, oceanographers compiled data on these equatorial currents from 44 transequatorial flights (aircraft were provided by the U.S. Navy and the National Oceanic and Atmospheric Administration), 4 shipboard surveys, 12 drifting buoys, and 5 instrumented moorings. Results indicate that monthly aircraft and shipboard surveys, together with limited current velocity measurements, are sufficient to describe the variations of equatorial currents. A 16-month field experiment beginning in January 1979 is now being planned on the basis of these results.

IDOE received the first study completed under the auspices of the Marine Science Affairs Program, a critical examination of the Soviet management of ocean affairs. Although the study focuses on the Soviet fishing industry, the findings are applicable to the full range of ocean activities.

American scientists and policymakers have tended to view Soviet ocean policymaking and management as a result of unified political leadership directing a successful, coordinated program of ocean-use expansion.

The study presents a sharply different picture. It finds that Soviet decision making and operations are more fragmented than unified and more competitive than coordinated. Despite the political structure, diverse interests and the promotion of individual or institutional objectives play a significant role in management and policy formulation. Overlapping authority, the

absence of mutual interests among agencies, and difficulties in coordination are all features of Soviet ocean policymaking and are severe enough to receive widespread attention in Soviet publications.

The major part of the planning for the program to follow the IDOE in 1980 was completed by a major workshop held in Seattle during September 1977. Some 80 participants, including marine and social scientists, laboratory administrators, Federal agency officials, industrial managers, and foreign scientists discussed the research needs and opportunities for large-scale, long-term oceanographic research during the 1980's. The basis for the discussions was a series of disciplinary workshops held in spring 1977 at the University of Rhode Island to identify promising new scientific directions for ocean research in the 1980s, plus extensive comments by mail from the marine affairs community.

A report summarizing the recommendations of the disciplinary workshops, *Ocean Research in the 1980's,* and the National Academy of Sciences report, *The Continuing Quest*, based on all the planning activities, were released during the summer of 1978.

The major finding is that a program of cooperative ocean research should evolve from IDOE, and that it support fundamental research designed to generate new scientific knowledge about the oceans and their interactions with the land and air. This new program would in turn provide a rational basis for understanding and governing human activities that impinge on the marine environment. The report envisages a broadening of the kinds of projects sponsored by the program, compared to those supported by IDOE. Like IDOE, however, the projects would be distinguished by their scientific quality and significance; an identifiable relation to issues of broad social significance; cooperation among scientists from different disciplines, institutions, and countries; and large size and long duration.

The National Science Foundation is now reviewing these recommendations. The results of this review will be described in next year's Progress Report.

ENVIRONMENTAL QUALITY PROGRAM

This program is designed to provide information on the quality of the marine environment and to assess and predict man's impact on the oceans through research on geochemical processes and marine pollution. The present program consists of four major investigations: Geochemical Ocean Sections Study (GEOSECS) makes detailed measurements of physical and chemical characteristics of ocean waters along Arctic to Antarctic transects; Pollutant Transfer Program investigates mechanisms and pathways by which pollutants are transported to and within the oceans; Biological Effects Program assesses the impact of selected pollutants on marine organisms; and Controlled Ecosystem Pollution Experiment (CEPEX) provides information on the effects of pollutants on pelagic marine communities contained in large plastic enclosures.

Geochemical Ocean Sections Study (GEOSECS)

GEOSECS is an international cooperative program involving geochemists from 14 U.S. universities. Investigators from Belgium, Canada, France, Federal Republic of Germany, India, Japan, and the United Kingdom are also participating in GEOSECS or are carrying out similar programs coordinated by the United States. The U.S. program involved the occupation of 121 oceanographic stations in the Atlantic and 147 stations in the Pacific. A similar study was conducted in the Indian Ocean to complete a baseline survey of the world oceans and confirm large-scale and small-scale mixing patterns found in the Atlantic and Pacific. Stations were occupied along the western side of the Indian Ocean, and the remaining stations were completed in April 1978. At each station, 15 chemical measurements were made aboard ship; an additional 20 will be obtained from samples analyzed in laboratories at 12 major universities.

Cruise tracks in the Indian Ocean were designed to include sampling of the circumpolar deep water along its 10,000-km boundary. The planned survey using three major north-south transects from India to the Antarctic continent will help to determine sources of water masses and their rates of movement (fig. 1).

Relationships between chemical and physical parameters that were found to be highly useful for predictive modeling in the Atlantic and Pacific Ocean are being confirmed and tested in the Indian Ocean. Knowledge of the carbon-oxygen system and the extent to which the oceans can absorb the products of fossil fuel combustion are being used in chemical assessment studies. Both shipboard and shorebased measurements from GEOSECS have contributed to present knowledge. (Table 1 lists tasks in this project.)

GEOSECS Data

GEOSECS data received during the period of this report are available from NODC as follows:

NODC Accession No.: 76–1522

Organization: Scripps Institution of Oceanography/GEOSECS Operations Group (GOG)

Investigators and Grant Nos.: W. Broecker (LDGO) GX–28164; D. W. Spencer (WHOI) GX–28161, OCE71–04195, OCE72–06421; A. Bainbridge (SIO/GOG) GX–28162, OCE71–04196; J. M. Edmond (MIT) GX–32976, GX–35033, OCE72–06432; L. I. Gordon GX–28167; H. G. Ostlund (RSMAS) GX–28165, OCE71–04199; H. Craig (SIO) GX–28163; M. Stuiver (UW) GX–28166, OCE71–04200; P. Brewer (WHOI) GX–33295; T. Takahashi (CUNY) GX–33293; T.-L. Ku (USC) GX–33292, OCE72–06418; R. Weiss (SIO) OCE76–18898

Project: GEOSECS Pacific (RV MELVILLE, 10 cruise legs) August 22, 1973, to June 10, 1974

Data: 147 ocean stations, 136 STDs, including oxygen, silicates, phosphates, nitrates. Data received in publication, *GEOSECS Pacific, Final Hydrographic Data Report 22 August 1973 to 10 June 1974,* RV MELVILLE, and in NODC-computer compatible magnetic tape.

GEOSECS Bibliography

Boyle, E. A., F. Sclater, and J. M. Edmond.
1976. On the marine geochemistry of cadmium. Nature 263:42–44.

Broecker, W. S., and T. Takahashi.
1977. Neutralization of fossil fuel CO_2 by marine calcium carbonate. *In*: N. R. Anderson and A. Malahoff (editors), The fate of fossil fuel CO_2 in the oceans, p. 213–241. Plenum Publ. Co., N.Y.

Chan, L. H., D. Drummond, J. M. Edmond, and B. Grant.
1977. On the barium data from the Atlantic GEOSECS Expedition. Deep-Sea Res. 24:613–649.

Chan, L. H., J. M. Edmond, R. F. Stallard, W. S. Broecker, Y. C. Chang, R. F. Weiss, and T. L. Ku.
1976. Radium and barium at GEOSECS stations in the Atlantic and Pacific. Earth Planet. Sci. Lett. 32:258–267. (GEOSECS Collected Papers: 1973–1976.)

Fine, R. A., and G. Ostlund.
1977. Source function for tritium transport models in the Pacific. Geophys. Res. Lett. 4:461–464.

Figure 1.—GEOSECS cruise track for Indian Ocean.

Gordon, L. I., E. A. Seifert, L. I. Barstow, and P. K. Park. 1974. Organic carbon in the Bering Sea Oceanography: An Update 1972–1974. Results of a seminar and workshop on Bering Sea oceanography under auspices of the U.S.-Japan Program, Office of International Programs, NSF, and Science Council of Japan, October 7 to 11, 1974. (Y. Takenouti and D. W. Wood, convenors). p. 239–244.

Kroopnick, P.
1975. Respiration, photosynthesis and oxygen isotope fractionation in oceanic surface water. Limnol. Oceanogr. 20:988–992.

Kroopnick, P. M., S. V. Margolis, and C. S. Wong.
1977. $\delta^{13}C$ variations in marine carbonate sediments as indicators of the CO_2 balance between the atmosphere and oceans. *In*: N. R. Anderson and A. Malahoff (editors) The fate of fossil fuel CO_2 in the oceans, p. 295–321. Plenum Publ. Co., N.Y.

Ostlund, H. G., H. G. Dorsey, and R. Brescher.
1976. GEOSECS Atlantic radiocarbon and tritium results. Tritium Lab. Rpt. No. 5, Rosenstiel School Mar. Atmos. Sci., Univ. Miami, 93 p.

Table 1.—U.S. institutions, investigators, and projects in GEOSECS

Institutions	Investigators	Projects
University of California, San Diego Scripps Institution of Oceanography	A. E. Bainbridge, H. Craig, and R. Finkel	Operations Group SIO Shipboard and Laboratory Measurements
The City University of New York, Queens College	M. Hoffert	Carbonate Chemistry of Seawater
Columbia University,. Lamont-Doherty Geological Observatory	W. S. Broecker and P. E. Biscaye	The Analysis of GEOSECS Samples Collected in the Indian Ocean for Ra–228, Th–228, and Suspended Particulates Interpretation of Carbonate Data
University of Hawaii	P. Kroopnick	Isotopic Measurements
Louisiana State University	L. M. Chan and J. S. Hanor	Barium Analyses in Ocean Waters
Massachusetts Institute of Technology	J. M. Edmond	High-Precision Barium, Copper, Nickel, and Cadmium measurements
University of Miami, Rosenstiel School of Marine and Atmospheric Science	H. G. Östlund	Radiocarbon and Tritium Measurements Administrative and Logistic Activities
University of South Carolina	W. S. Moore	Measurement of Ra–228 in Seawater
University of Southern California	T. L. Ku	Radium Analysis
University of Washington	M. Stuiver	C-14 Ocean Water Analysis
Woods Hole Oceanographic Institution	D. W. Spencer, P. G. Brewer and W. J. Jenkins	Lead, Polonium, Helium, and Neon Analyses Water Library
Yale University	K. K. Turekian	Lead, Polonium, and Silicon Analyses
	M. E. Fiadeiro	Three-Dimensional Modeling of Tracers in the Ocean

Pollutant Transfer Program (PTP)

Processes that transport pollutants from land sources to the oceans and accumulate pollutants in discrete parts of the marine environment are being investigated. Objectives of the studies are to: (1) identify important pathways and mechanisms, (2) evaluate major environmental factors that influence transfer processes, and (3) develop principles governing the transfer of pollutants. Attention is being focused on several major ocean interfaces: air-sea, sediment-sea, river-sea, and particulate-sea. Tasks in this part of the PTP are listed in table 2.

Investigations of organic carbon in marine aerosols show that the major mass of the organic carbon is found on particles with radii less than $0.5 \mu m$. The data shown in figure 2 suggest that this distribution is similar over the North and South Pacific and North Atlantic. This small-particle distribution suggests that most of the particulate organic carbon in the marine atmosphere may result from gas-to-particle conversion reactions.

Studies of arsenic (As) in the marine atmosphere have shown that while an ambient vapor phase of As is only a small fraction of the As present on particles, volatilization processes probably provide the major sources of atmospheric As. However, this vapor phase apparently has a very short residence time in the atmosphere. The major global sources for atmospheric As appear to be volcanism and human sources, particularly smelting, coal combustion, and agricultural pesticide applications. The biosphere may also be a significant global source for atmospheric As.

An investigation of the global atmospheric cycle of phosphorus (P) showed that the major source of atmospheric particulate P was crustal weathering; the ocean and human sources accounted for about 10 percent of the weathering source. It is estimated that 10^{12} g/yr of phosphorus from actual weathering and from human sources is transported annually to the ocean, of which about $\frac{1}{5}$ is soluble. This soluble P accounts for 10 percent of the estimated marine input of dissolved P into the ocean.

Investigations of the copper, zinc, and iron concentrations on atmospheric sea salt particles produced artificially in a closed system on Narragansett Bay, Rhode Island, indicate that relative to sodium the concentrations of these elements are several hundred times higher on sea salt particles than in the bulk seawater from which they are produced. If these results are also applicable to open-ocean conditions, enrichment of copper and zinc during the production of these particles by bursting bubbles may be a significant source of these elements, which are found in ambient marine aerosols over the world ocean. Crustal weathering still appears to be the primary source of iron in the atmosphere, however. These studies were done using the Bubble Interfacial Microlayer Sampler (BIMS) shown in figure 3.

Sampling and analytical techniques were developed and refined during the past year that enabled successful measurement of cadmium, copper, nickel, manganese, and zinc throughout the water column. Because contamination problems associated with the measurement of zinc are particularly severe, accurate profiles for this element did not exist. Zinc concentrations (10-600 ng/l) are considerably lower than previous estimates

Table 2.—U.S. institutions, investigators, and projects in Pollutant Transfer Program

Institutions	Investigators	Projects
California Institute of Technology	C. C. Patterson	Determination of Input and Transport of Pollutant Lead in Marine Environments Using Isotope Tracers
University of California, Bodega Marine Laboratory	R. Risebrough	Fluxes of Organochlorine Pollutant Through the Marine Environment
University of California, Scripps Institution of Oceanography	E. Goldberg	Low Temperature Volatilization of Heavy Metals from Crustal Rocks
University of Georgia, Skidaway Institute of Oceanography	H. L. Windom	The Transfer of Heavy Metals Through the Inner Continental Shelf to the Open Ocean
Harvard University, Bermuda Biological Station, Inc.	J. N. Butler and B. F. Morris	Transfer of Petroleum Residues in Sargasum Communities and the Water of the Sargasso Sea
University of Rhode Island	R. A. Duce	Anomalously Enriched Elements in the Marine Atmosphere: Sources, Distribution, and Fluxes
	C. E. Olney and T. F. Bidleman	Atmospheric Transport and Deposition of High Molecular Weight Chlorinated Hydrocarbons on the Ocean Surface
San Jose State University	J. H. Martin	Cadmium Transport to the Open Pacific Ocean Via the California Current
Texas A & M University	C. S. Giam	Phthalate and Chlorinated Hydrocarbon Transfer Processes in the Marine Environment
Woods Hole Oceanographic Institution	G. R. Harvey	A Detailed Inventory of Concentration-Fluxes of the Major Halogenated Pollutants at 2 Sites in the Northwest Atlantic

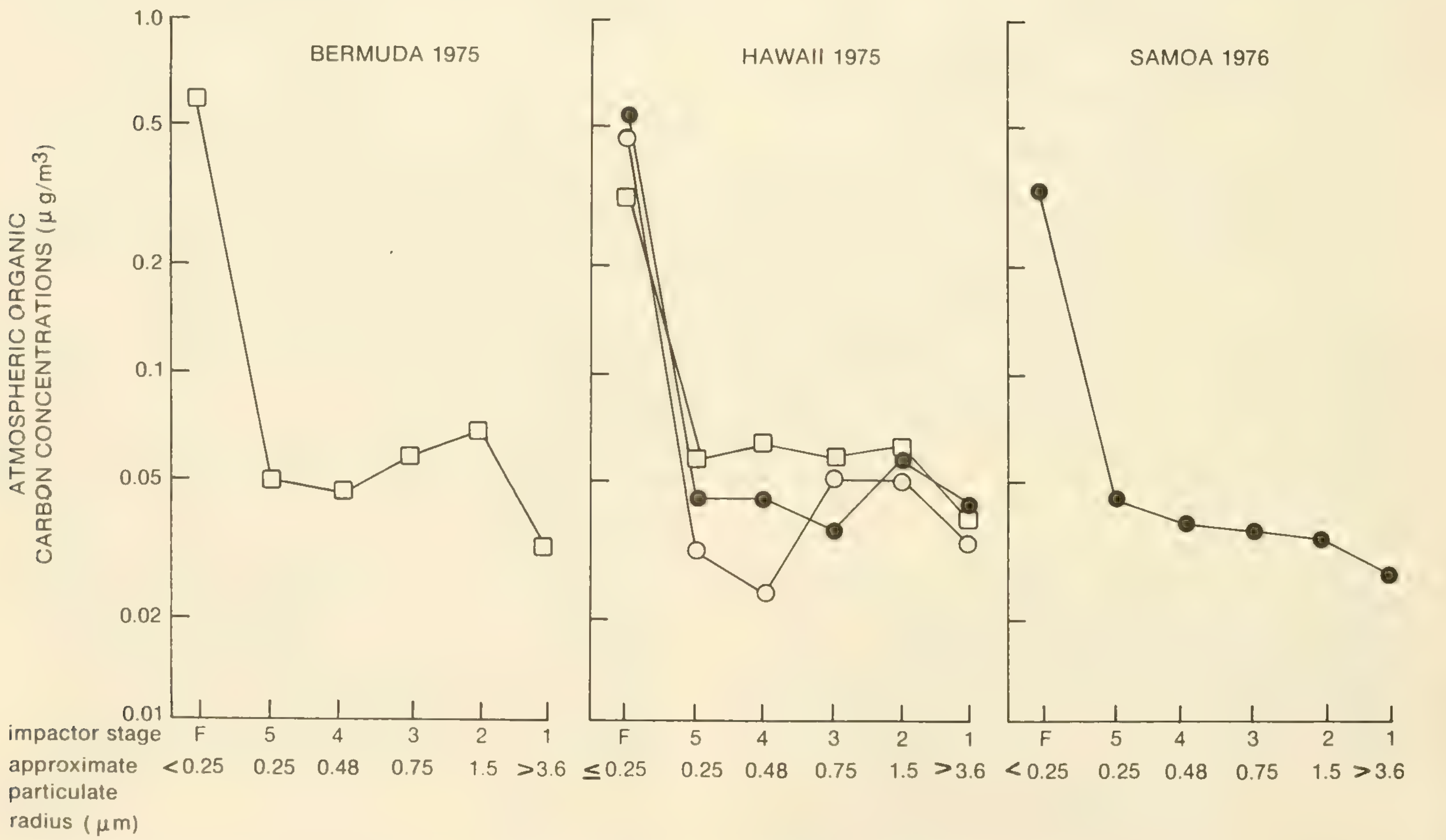

Figure 2.—Size distribution of organic carbon in atmospheric particulate matter collected at remote marine locations.

of 1 to 30 $\mu g/l$, and its vertical distribution (surface depletion, deep enrichment) is very similar to that of a major plant nutrient—silicate (fig. 4).

Fluxes of elements in association with sinking plankton detritus were measured with particle interceptor traps at three depths (range = 50-100 m) in coastal and open-ocean Pacific waters. Observed rates of change for carbon, nitrogen, and phosphorus and inferred rates of oxygen change varied widely in relation to surface productivity. For example, oxygen utilization rates calculated from the carbon flux data were as high as 650 $\mu l/l^{-1}/year^{-1}$ at 100 m under upwelling conditions and as low as 18 $\mu l/l^{-1}/yr^{-1}$ at 1,000 m in the open ocean. The investigators also concluded that quantities of passively sinking particulate carbon, nitrogen, and phosphorus appear to be in excess of the amounts required to meet the nutritional needs of the midwater zooplankton, even in the open ocean when fluxes are relatively low.

Continuous culture experiments showed that natural populations of marine phytoplankton concentrate ionic copper. Concentration of copper was from two to six times higher in cells from cultures containing 1 to 2 μg copper per liter. Additional observations were:

(1) Effects of copper concentration varied between species;

(2) Cell division was inhibited in one diatom species, *Leptocylindus danicus;*

(3) Copper was lethal to another diatom, *Ceratulina bergonii*;

(4) Intracellular processes of chlorophyll synthesis or carbon production were not inhibited;

(5) Chlorophyll per cell increased slightly (thought to be owing to reduction in cell division);

(6) Primary production in the diatom, *Skeletonema costatum,* did not decrease (only species on which this was tested).

Cultured phytoplankton take up arsenic (As) in a period of 2 to 3 days when grown in a media enriched with 5 to 25 μg As(V) per liter (fig. 5). Both the inorganic and methylated As levels in the cells increased by about 50 percent in *Skeletonema costatum.* The As content of *Peridinium trochoidium* increased drastically under the same conditions, with cell concentrations increasing from 5 to over 63 ppm. Cultures enriched with As(III) exhibited similar uptake; however, enrichment with dimethylated arsenic (DMA) caused no significant uptake of As.

The As speciation in the culture media changed significantly during the course of the experiment in cultures that had been enriched with As(V) or As(III). Addition of DMA caused no changes in As speciation other than those caused by the addition itself.

The continuing investigation of organic pollutants in the Gulf of Mexico has established that phthalic acid ester plasticizers (PAES) are a new class of marine pollutants. Phthalate esters are found in virtually all samples from the Atlantic Ocean and the Gulf of Mexico. For example, samples of water, sediment, and air from the Gulf of Mexico were found to contain di-(2-ethylhexyl)phthalate (DEHP) at concentrations often higher than the well-known PCBs and DDTs. However, the concentration of PAES in biota was lower than that of PCB or DDT, suggesting that biological degradation may be a significant removal mechanism for phthalates in the marine environment (fig. 6).

Preliminary analyses show that as much as 70 percent of the phthalates in the Gulf of Mexico have been transported via the atmosphere. The rates and mechanisms of organic pollutant transport depend on the class compound. For example, organic pollutants are transported to the atmosphere both in association with particles and as a vapor. PCBs and DDTs are transported primarily in the vapor phase; however, DEHP appears to be distributed nearly equally between the vapor and particulate

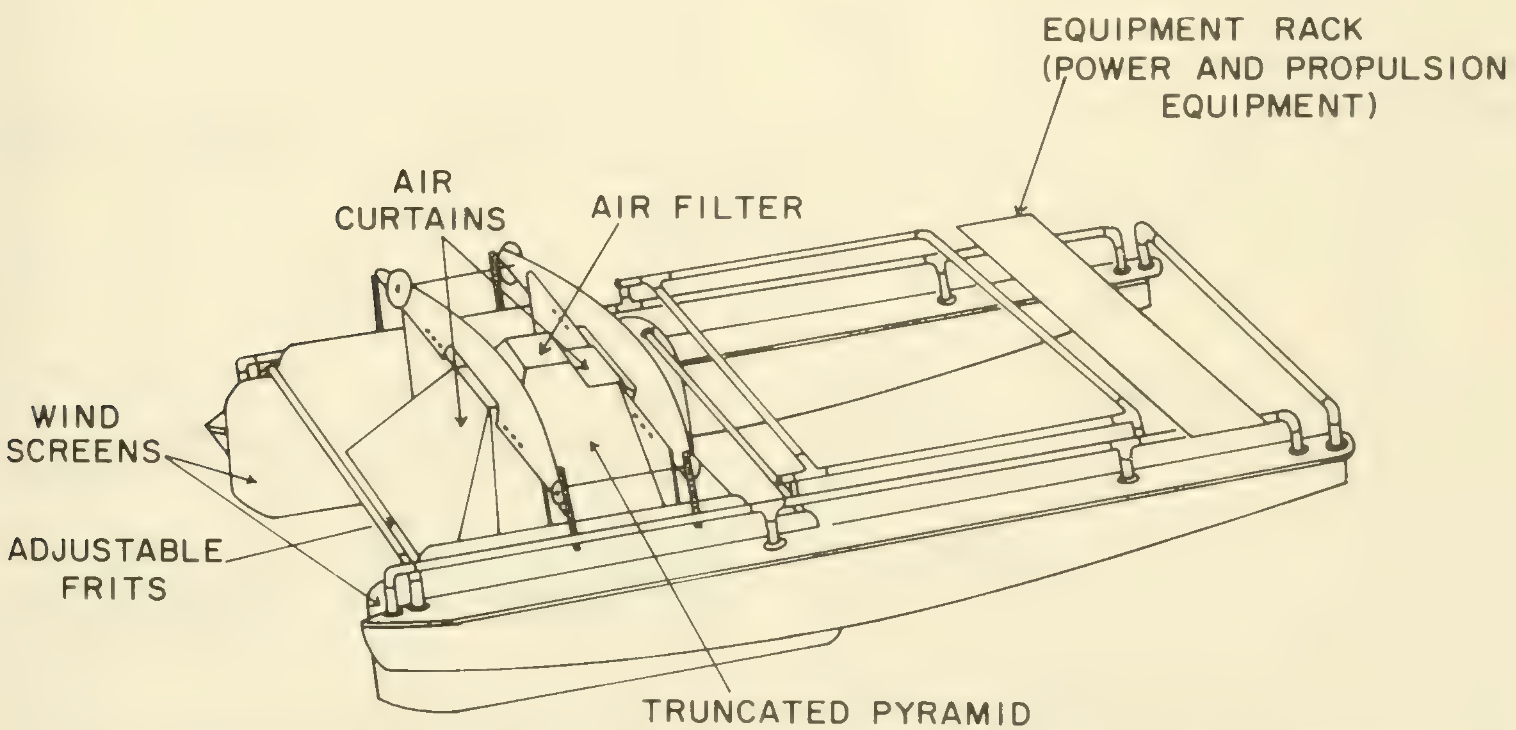

Figure 3.—The Bubble Interfacial Microlayer Sampler (BIMS) suspended between the twin hulls of a 4-meter long catamaran.

phase. This difference is important in evaluating the flux of organic compounds to the ocean.

Sea-Air Exchange (SEAREX)

A new collaborative project on sea-air exchanges (SEAREX) is examining the importance of organic and inorganic pollutant fluxes to the ocean from the atmosphere. Simultaneous measurements of different compounds in the air, rain, and dryfall are being made in remote marine locations to produce direct measurement of pollutant fluxes.

Early measurements with a collector in towers on Bermuda showed a dramatic change in chemical composition of trapped particles as wind direction changed. Specifically, winds blowing from land carried particles rich in iron. Over the next 2 years, SEAREX investigators hope to quantify the airborne movement of certain heavy metals and natural and manmade organic compounds. This effort will allow them to identify the sources of these materials and to understand the mechanisms by which the substances cross air-sea boundaries.

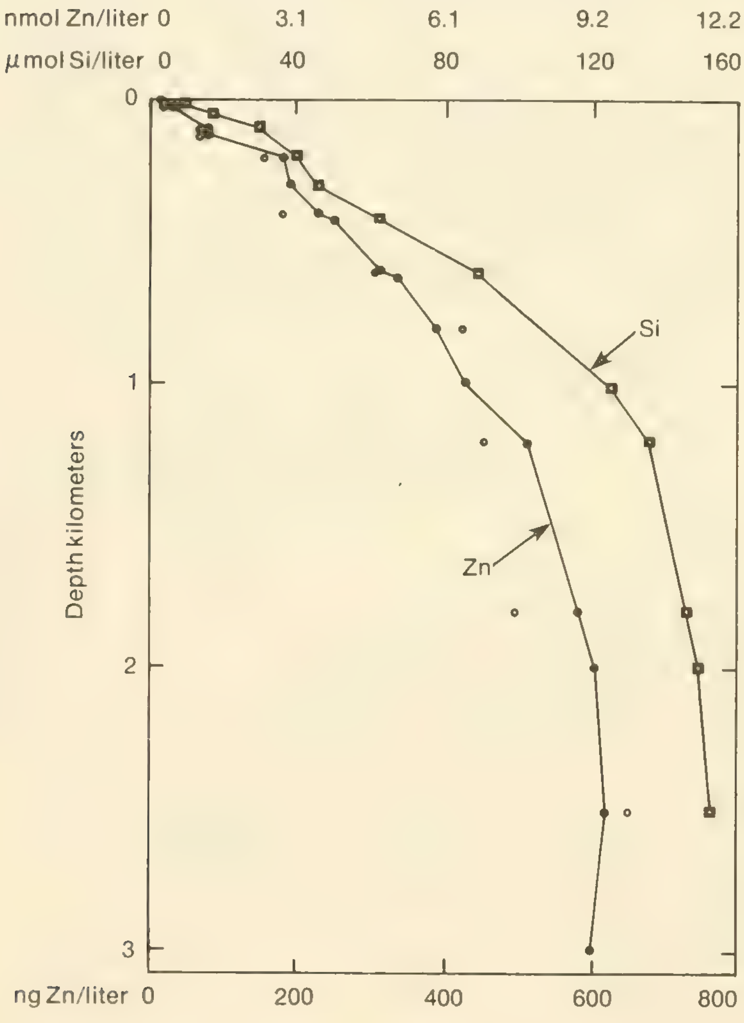

Figure 4.—Depth profiles of zinc and silicon off the central California coast. For zinc, closed circles signify organic extractions; open circles designate separations on a chelex column.

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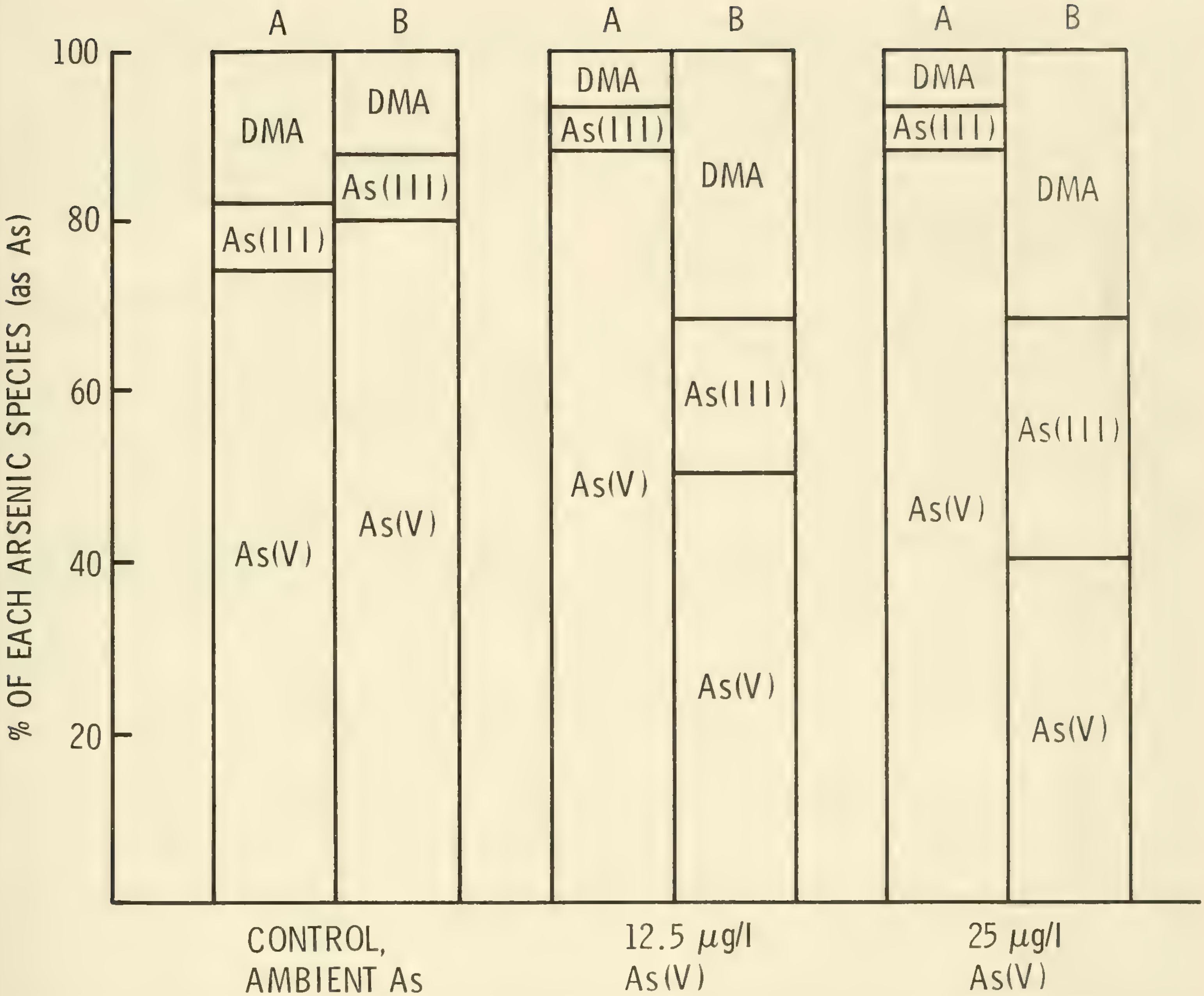

Figure 5.—Arsenic speciation in culture media. Each species displayed as percent of total As. Bar A: stock culture media in which no growth has taken place. Bar B: the same media, after 1-week's growth. (DMA is dimethyl arsenic; As (III) and As (V) signify arsenic in the plus three and five oxidation states, respectively.)

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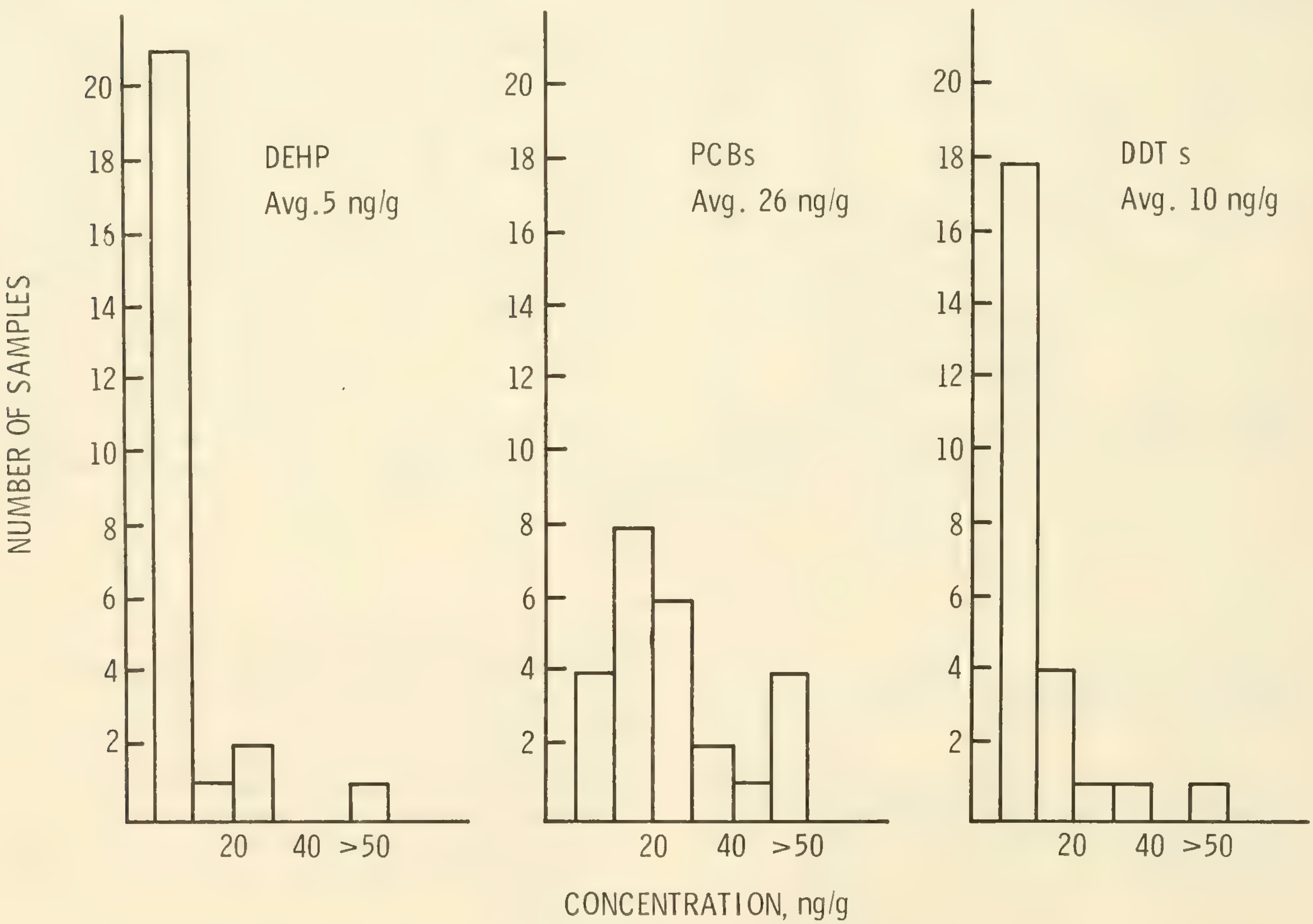

Figure 6.—Concentration of DEHP, PCBs, and DDTs in the biota from the Gulf of Mexico.

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Biological Effects Program (BEP)

The major emphasis in the final year of the Biological Effects Program (BEP) was to find biological indicator species that could be used as an early warning of pollutant-induced perturbations in the open ocean. This focus evolved from the initial studies that began in 1973. At that time, several investigators initiated laboratory experiments to evaluate sublethal, low-level effects of trace metals, petroleum, chlorinated hydrocarbons, and phthalates on the growth, behavior, and biochemical processes of several classes of marine organisms. The objectives of this program were to determine the effects of various types and levels of pollutants on the life history stages and physiological processes of a wide range of species. Table 3 lists the projects in this program.

Results from these projects indicate that several pollutants are acutely toxic in the parts-per-million range to bacteria, phytoplankton, and higher marine organisms. Generally, heavy metals (mercury, copper) and chlorinated hydrocarbons are found to be more toxic than petroleum hydrocarbons. Also, either whole or water-soluble extracts of fuel oils are more toxic than crude oils in either form. Finally phthalates, which are more abundant than PCB or DDT, appear to be less toxic to higher organisms.

Specific results from these various projects indicate that the toxicity of aromatic hydrocarbons to marine bacteria increased inversely with solubility. Thus, high molecular weight, relatively insoluble hydrocarbons such as benzpyrene may be just as toxic as the lower molecular weight, more soluble hydrocarbons such as naphthalene.

Photosynthesis by marine microalgae was found to be immediately and severely inhibited by low-dose rates (1 to 10 μg water-solubles per mg dry algae) of oil water-solubles. Differential effects on the rate of photosynthetic oxygen evolution and pH increases in cell suspension suggest that different oils have different toxicity mechanisms. These short-term studies indicate that the primary toxic effect of oil and water-solubles on microalgae may be through direct action on the energy-yielding electron transport systems.

Effects studies of the water-solubles of six oils on the survival and growth rate of the embryonic and larval stages of the quahog clam, *Mercenaria* sp., showed that the median lethal concentrations (LC_{50}) of six oils ranged from less than 0.10 ppm to 10 ppm in 6-day exposure tests. Ten-day exposure periods decreased the LC_{50} values of the least toxic crude oils to about 2 ppm. Larvae surviving exposure to water-soluble fractions of the various oils grew at slower rates than comparable control larvae.

Table 3.—U.S. institutions, investigators, and projects in Biological Effects Program

Institutions	Investigators	Projects
University of Alaska	P. B. Reichardt and D. K. Button	Lability of Aromatic Hydrocarbons and Their Nonlethal Effects on Marine Organisms
University of Delaware	M. R. Tripp	Histopathology of Benthic Invertebrates
Florida State University	J. A. Calder	Investigations of Breakdown and Sublethal Biological Effects in Trace Petroleum Constituents in the Marine Environment
University of Georgia, Skidaway Institute of Oceanography	R. F. Lee	Fate of Petroleum Hydrocarbons in Marine Food Web
Texas A & M University	J. M. Neff	Sublethal Effects of Selected Heavy Metals and Organic Compounds on Organisms From the Gulf of Mexico
	C. S. Giam	Biological Effect of Phthalates and Chlorinated Hydrocarbons in Biota from the Gulf of Mexico
	W. M. Sackett	Fate, Spatial, and Temporal Distribution of Petroleum-Derived Organic Compounds in the Ocean, and their Sublethal Effects on Marine Organisms
	H. Kleerekoper	Subacute Effects of PCBs and Copper Ions in Locomotor and Orientation Behavior in Certain Marine Fishes
University of Texas, Marine Science Institute	J. A. C. Nichol and C. Van Baalen	Marine Petroleum Pollution: Biological Effects and Chemical Characterization
Woods Hole Oceanographic Institution	J. J. Stegeman	Xenobiotic (Hydrocarbon) Metabolism by Mixed Function Oxidases in Estuarine, Coastal, and Open Ocean Fish Species

In other experiments, microorganisms that were known not to metabolize hydrocarbons showed a bioconcentration of these hydrocarbons from the dissolved phase in seawater of about 2,000-fold, based on cell weight.

Fluorescence microscopy showed that most of the bioconcentrated hydrocarbons were located in the cell mitochondria, with some in the cell cytoplasmic membrane. Continuous culture populations of algae were sensitive to saturating concentrations of chlorinated biphenyl. Sensitivity was significantly greater when the algae were paired with the yeast, *Rhodotorula rubra*, a marine isolate. As shown in figure 7, 2 micromolar dichlorobiphenyl caused dramatic changes in the algal population distribution and limited nutrient content.

Continuous culture systems were also sensitive to solvents

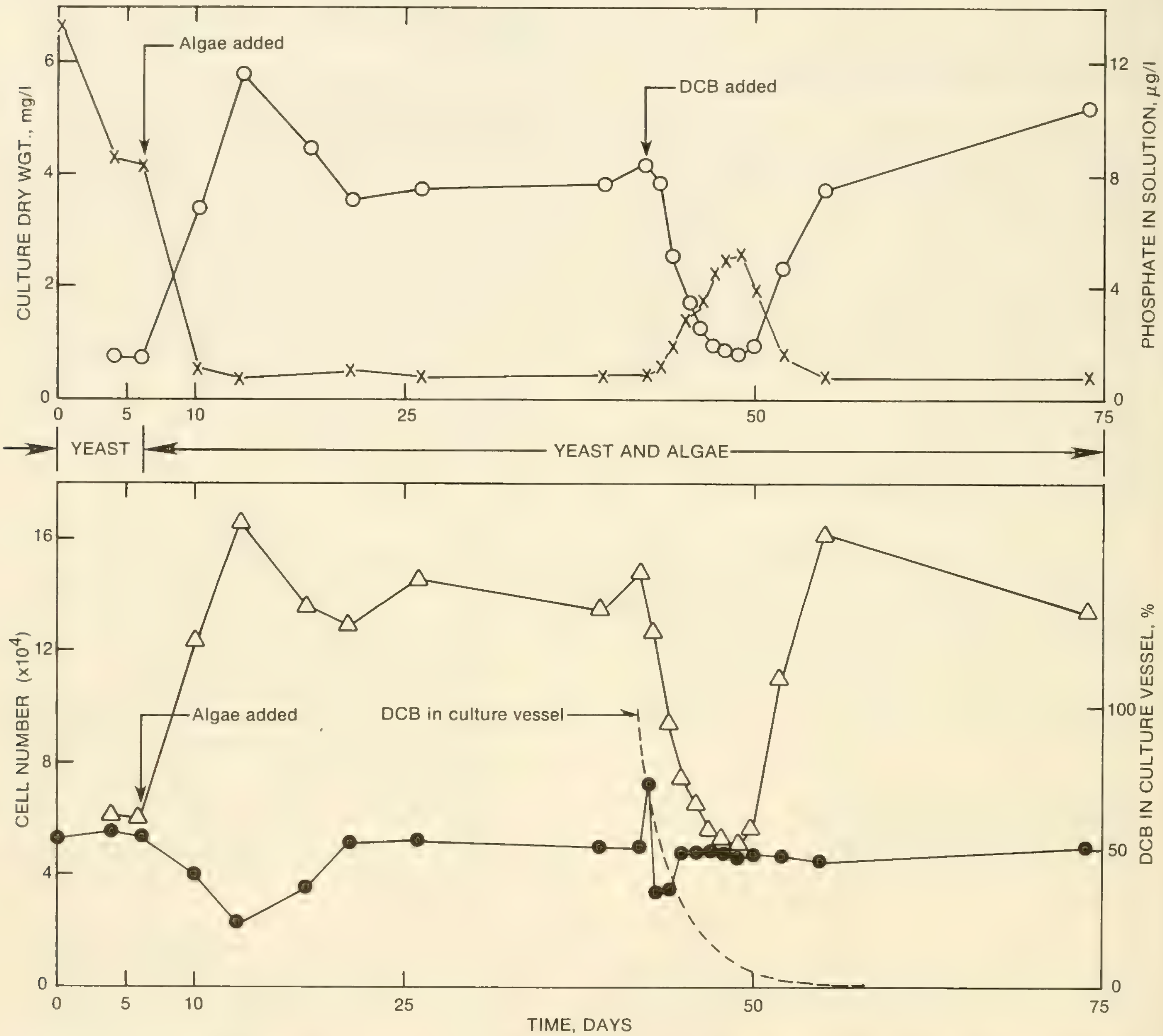
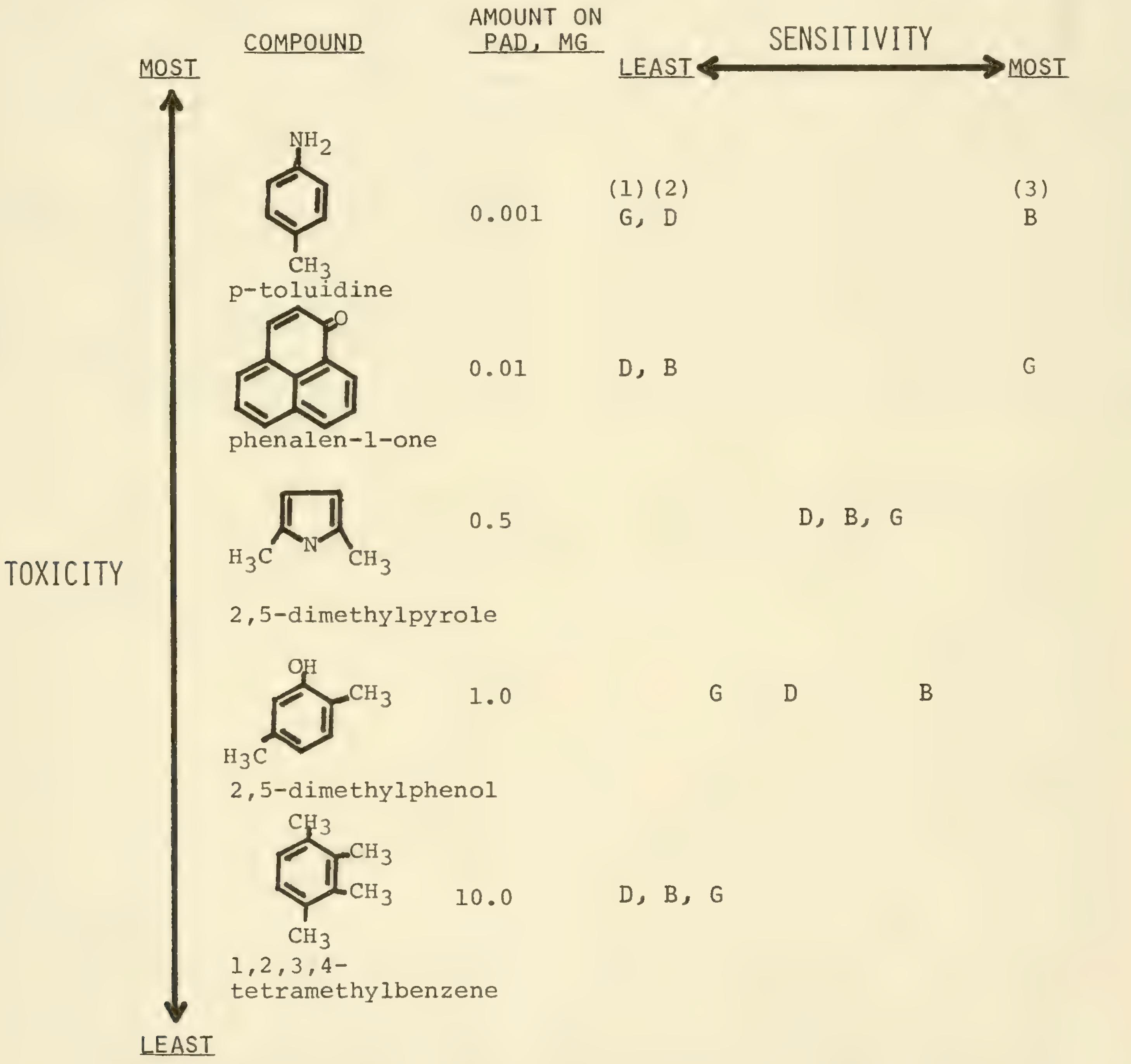


Figure 7.—Dichlorobiphenyl addition to a gnotobiotic continuous culture at steady state. On day 6, small inocula of *Selenastrum capricornutum* (algae) were added to the carbon-limited continuous cultures of *Rhodotorula rubra*. The concentration of phosphate in solution reflects phosphate-limitation of the algae. On day 43, when the system was at steady state, approximately 2 micromolar 2,4′ dichlorobiphenyl (DCB) was added to the dual culture system. The culture dry weight and total cell numbers decreased, while phosphate in solution increased until less than approximately 0.2 micromolar dichlorobiphenyl remained in the culture vessel. The yeast viable counts oscillated slightly immediately after the addition, but soon returned to normal. Dilution rate (growth rate) = 0.36 day^{-1}. Residence time of culture vessel contents = 2.78 days. 0——0 dry weight of yeast + algae. x——x phosphate in solution. △——△ total cell count of yeast + algae. •——• viable cell count of yeast.

such as toluene—a prime constituent of treated oil tanker ballast water. Yeast populations were fairly insensitive to submillimolar levels, showing only a slight stimulation in leakage of internal cellular constituents. Algae populations, on the other hand, were sensitive to toluene levels as low as 50 micromolar.

Crude oils, either as water-solubles or as whole oils, did not prove very inhibitory to algal growth. However, water-solubles from fuel oils can be quite lethal to microalgae depending upon the sample and the algae used as test organisms. Figure 8 shows that two compounds identified in the water-solubles, p-toluidine and phenalen-1-one, were highly toxic to a blue-green and a green alga, respectively. The other three compounds were much less toxic, and the algal response was more uniform. Whole fuel oils added directly to the algal culture medium were also toxic. Again, toxicity varied with the fuel oil sample and the test organism. The compounds responsible for the toxicity of whole fuel oils have not yet been identified; however, they should be different from and of a more lipophilic nature than the compounds in the water-soluble fractions. Water-soluble extracts of No. 2 fuel oil are lethal to benthic crustaceans at 4 ppm for



1) Green alga, Chlorella autotrophica, strain 580
2) Diatom, Cylindrotheca sp., strain N-1
3) Blue-green alga, Agmenellum quadruplicatum, strain PR6.

Figure 8.—Algal lawn assay of pure compounds for toxicity.

short exposure periods (fig. 9). Growth and fecundity are reduced at lower levels, 0.6 and 0.2 ppm, respectively. When adults are exposed to low levels of the oil for 1 month, there is high mortality among the young; more than 70 percent in 5 weeks (fig. 10). When constituents of the oil were tested, it was found that certain combinations, (e.g., naphthalene and benzene) were more toxic than single compounds, suggesting synergistic effects.

In conjunction with CEPEX, experiments were made on petroleum hydrocarbons by adding a dispersion of Prudhoe crude oil to a quarter-scale enclosure (about 60,000 l). The results show that the concentration of the different aromatics in water, zooplankton, oysters, and bottom sediments decreased at an exponential rate, because of evaporation, photochemical oxidation, microbial degradation, and sedimentation (fig. 11).

Results of studies investigating the effects of pollutants on embryonic and larval development, growth, and bioenergetics of marine invertebrates and fish show that the embryo-larval stages of the fish, *Fundulus heteroclitus*, were moderately tolerant to water-soluble fractions (WSF) of No. 2 fuel oil, showing an LC_{50} of about 1.5 ppm total hydrocarbons. The early embryonic stages were more sensitive to oil than were later embryonic and larval stages. The instantaneous uptake rate and release rate of C^{14}-naphthalene were highest in 2-day-old embryos and decreased in a linear fashion as development progressed. Larvae hatching from hydrocarbon-exposed embryos were smaller than controls, and slightly stressful temperatures and salinities greatly increased the sensitivity of these fish embryos to hydrocarbon exposure.

Larvae of the mud crab, *Rhithropanopeus harrisii*, were exposed continuously during development to naphthalene or phenanthrene at different combinations of temperature and salinity. Phenanthrene was substantially more toxic than naphthalene. Slightly stressful temperature/salinity regimes increased larval sensitivity to naphthalene and phenanthrene as shown by decreased survival to metamorphosis, increased duration of larval development, increased respiratory rates of exposed larvae, and increased sensitivity to acute salinity stress. The results indicate that sublethal hydrocarbon stress shunted assimilated energy away from growth processes to maintenance functions (fig. 12).

Larvae of grass shrimp, *Palaemonetes pugio*, were exposed continuously during development to several combinations of temperature, salinity, and zinc concentration. The larvae were most sensitive to zinc at low salinity and high temperature, and zinc exposure significantly modified respiratory responses of the larvae to stressful temperature/salinity regimes.

Experiments on the effects of pollutants on the corticosteroid stress response in marine fish and ascorbic acid metabolism in marine fish and invertebrates show that chronic exposure to low levels of phenanthrene or dichloronaphthalene produced unexpected fluctuations in whole body free ascorbic acid levels in fish embryos, juvenile fish, and grass shrimp. These fluctuations in free ascorbate levels may represent a mobilization of ascorbate from the ascorbate-2 sulfate pool. Methods are currently being developed for the simultaneous analysis of ascorbate and ascorbate-2 sulfate in tissues to test this hypothesis.

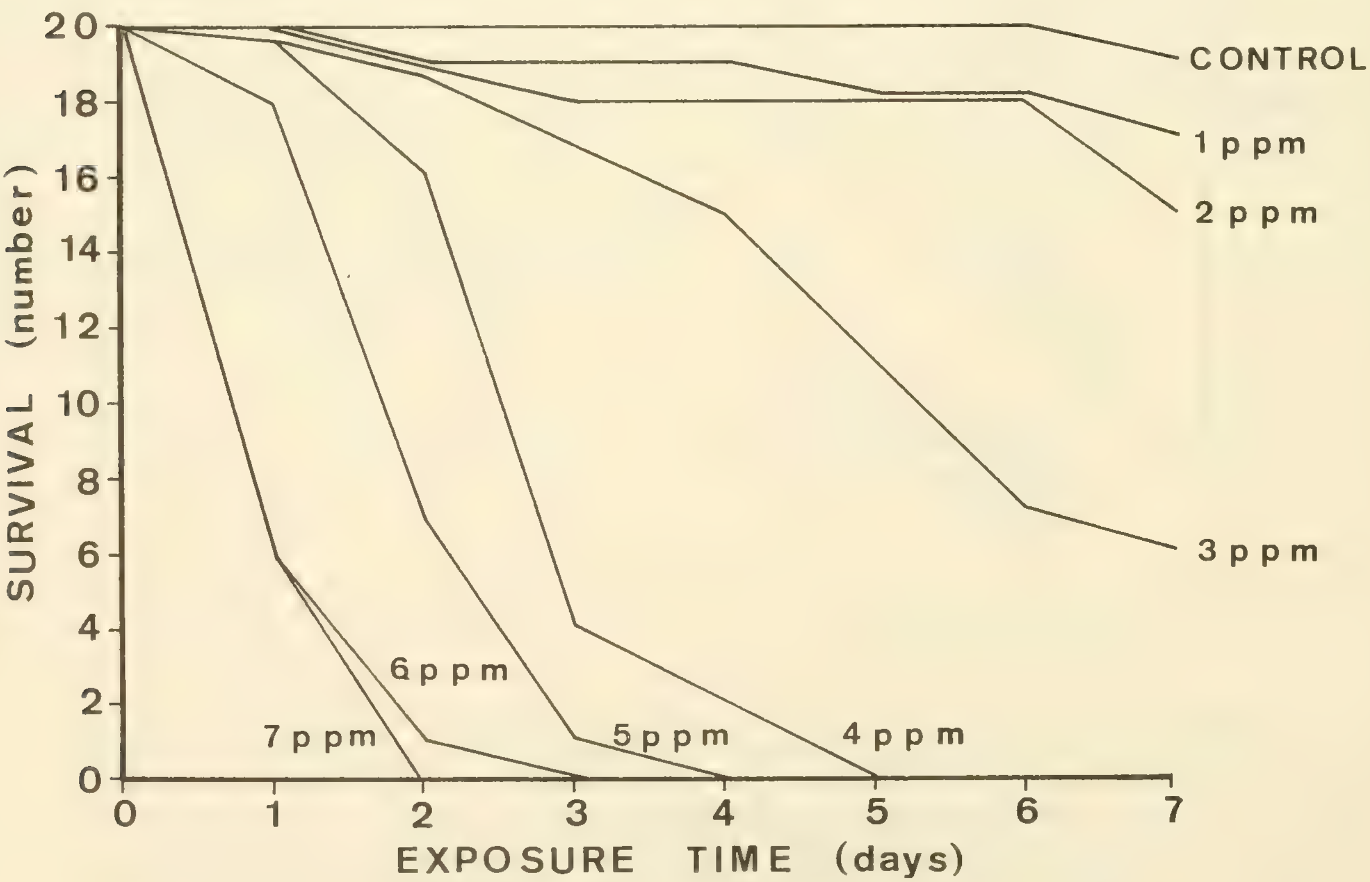


Figure 9.—Survival of amphipods (*Elasmopus pectenicrus*) in the water soluble fraction of No. 2 fuel oil.

Other experiments used morphological, physiological, and biological criteria to assess the effects on two species of clams (*Mercenaria mercenaria* and *Mya arenaria*) of selected hydrocarbons (pentachlorophenol, hexachlorobenzene, and benzene) which are dissolved in acetone and injected into the clams.

Histological examination by light microscopy reveals necrosis and inflammation at the injection site owing to acetone damage; test hydrocarbons have no detectable effect. Pentachlorophenol injections increase hemolymph concentrations of acid phosphatase and alkaline phosphatase in both *Mya* and *Mercenaria*; hexachlorobenzene causes a slight increase in alkaline phosphatase. Electrophoresis of hemolymph protein shows changes in protein patterns for both clams.

Additional effects studies using phthalate ester plasticizers, a new class of marine pollutants, were made to determine their toxicity to marine organisms. Moderate effects on growth, development, and mortality were detected when adult killifish, larval grass-shrimp, and mud crabs were exposed to phthalate ester plasticizers. However, toxic effects did occur in certain phytoplankton species including blue-green algae, green algae,

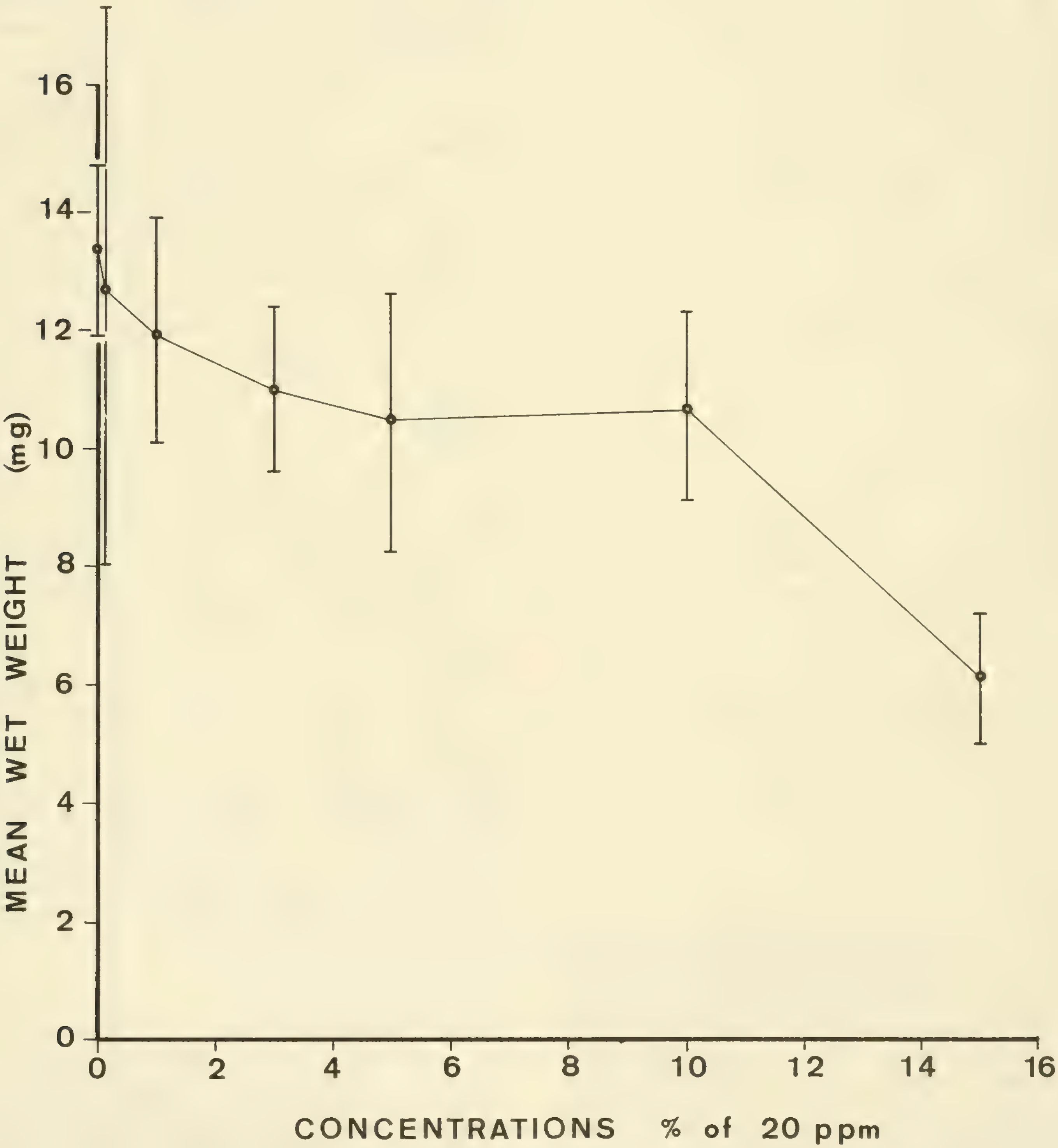


Figure 10.—Growth of an isopod *(Sphaeroma quadridentatum)* in the water soluble fraction of No. 2 fuel oil.

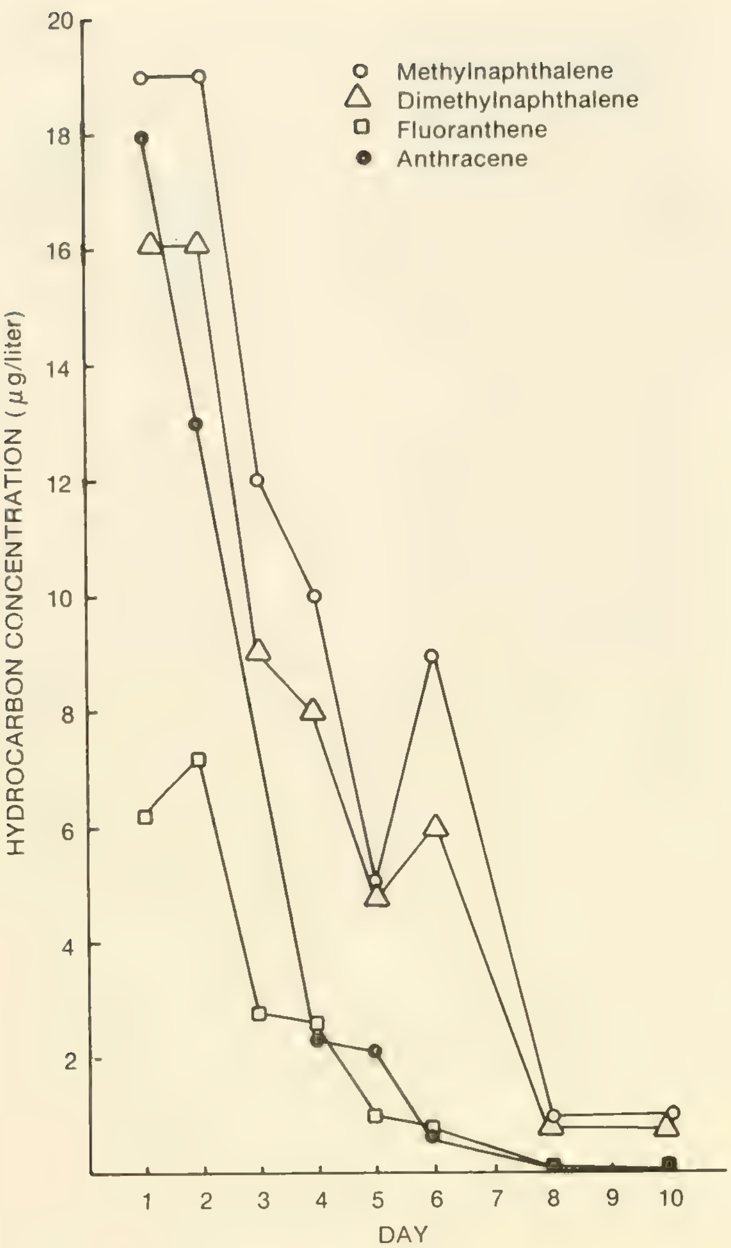


Figure 11.—Decrease in concentration of petroleum hydrocarbons added to CEPEX bags.

and diatoms.

In general, the lower alkyl phthalates, such as di-*n*-butyl phthalate, produce more toxic effects than di-(2-ethylhexyl)-phthalate. Uptake studies with adult fish yielded low bioaccumulation factors for the phthalates, relative to the chlorinated hydrocarbons. One implication of this finding is that slow uptake or rapid metabolism and excretion may be responsible for the low toxicity of phthalates to higher organisms; this finding would also explain the low levels present in biota samples from the Gulf of Mexico.

Experiments also focused on a characterization of the mixed-function oxygenase (MFO) system in two marine invertebrates, the blue crab and a polychaete worm. The MFO system is responsible for the metabolic modification of many foreign compounds, such as hydrocarbons or pesticides, in animals. Compared with the parent compound, the metabolite is more water soluble and can be more easily excreted from the animal. In the worm, enzyme activity was found in the lower intestine; in blue crabs, activity was in the stomach and green gland. In the blue crab, the enzyme activity of the green gland was found to vary with different stages of maturity and molt cycle (fig. 13). The green gland, generally thought of as an excretory organ, may also function to regulate molting hormone levels. This may explain the difficulty crabs and other crustaceans have in molting after exposure to certain pollutants. In worms continually exposed to crude oil, we find higher levels of MFO after the third generation. Thus, crude oil may influence development of a genotype that is resistant to the effects of oil.

In a similar study, MFO characteristics were studied in more than 30 species of fish. Estuarine and coastal species (e.g., winter flounder, two species of mummichogs, bluefish, striped bass, menhaden, and mackerel) have moderate to high level of MFO activity; however, the MFO properties of several of these species show metabolic and inhibitor response characteristics that are different from mammalian systems. On the other hand, MFO activity in midwater, open-ocean fishes (e.g., viper fish and hatchet fish), which was observed for the first time, was generally very low compared to coastal species.

In winter flounder and the mummichog, *Fundulus heteroclitus*, one or more properties of MFO were found to vary with sex, season, or size. The observed patterns of variation confirm that there are multiple forms of MFO systems within a given fish species.

In addition, the levels of MFO were consistently found to be higher in estuarine fish from areas contaminated by organic pollutants, including petroleum. For instance, fish from Wild Harbor, Massachusetts, the site of a 1969 oil spill, are still being affected 8 years after the spill. The results generally indicate that while there may be a correlation between MFO activity and environmental contamination, the conditions under which use of MFO as environmental indicators may be validly interpreted are limited.

Observations of the locomotor behavior of certain fish species were made to determine the effect of short-term exposure to increased but subacute concentrations of copper ions. Temporary exposure to increased copper levels drastically altered the locomotor behavior of sheepshead fish. Overall activity was greatly increased, and the pattern of movements in the tank, which depends on the animal's turning behavior and is under central nervous control, underwent distinct changes. Increased activity was also observed in other fish species (spadefish, triggerfish, pinfish, sea catfish, and croaker) exposed to increased copper levels.

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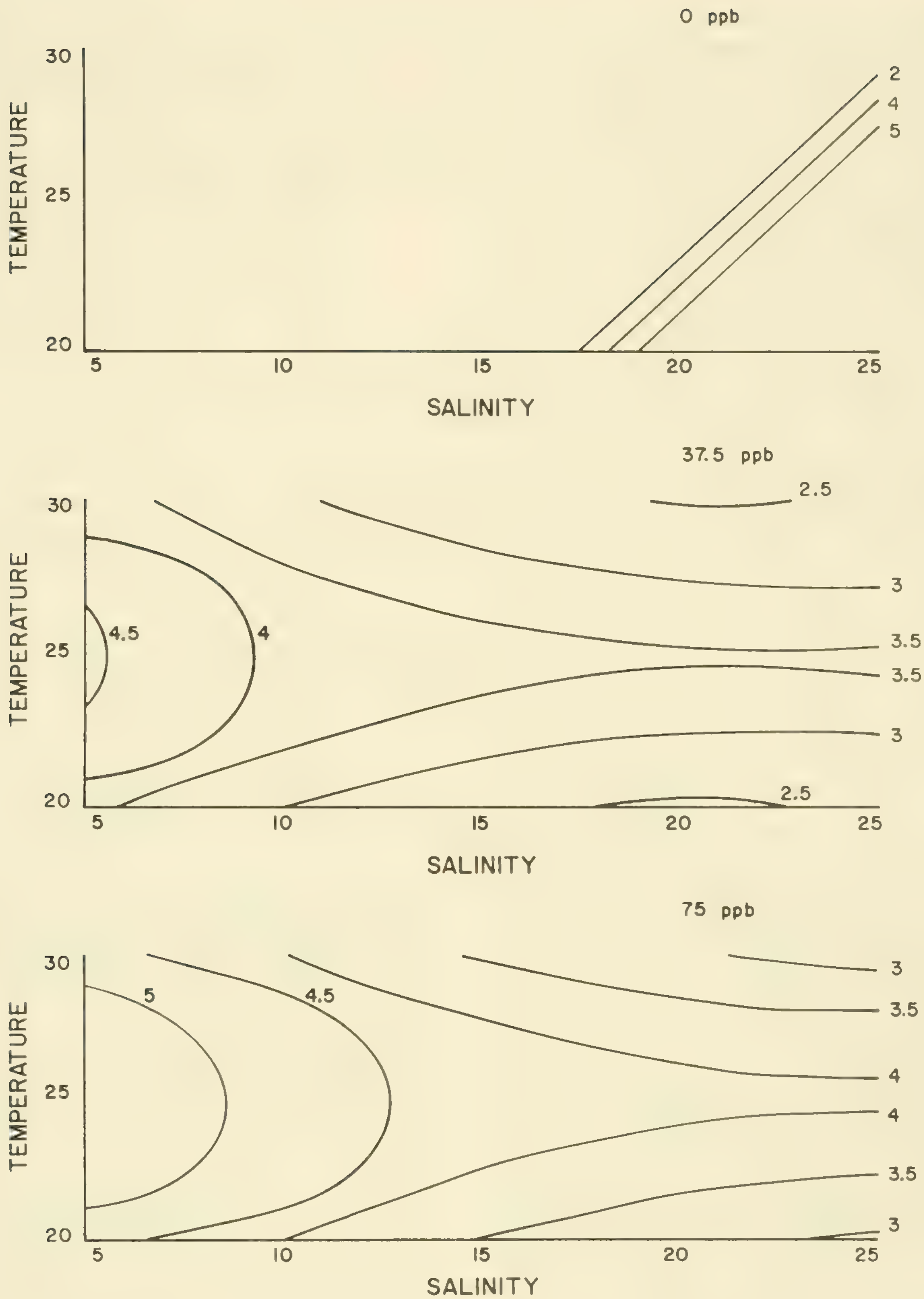

Figure 12.—Response surface diagram showing predicted respiration rates of the megalops of *Rhithropanopeus harrisii* acclimated to the test salinities and temperatures and exposed to phenanthrene. Exposure to 37.5 or 75 ppb phenanthrene causes an increase in the sensitivity of the megalops to salinity and a decrease in its sensitivity to temperature. Contour values are given in ml 0_2/g dry wt/hr.

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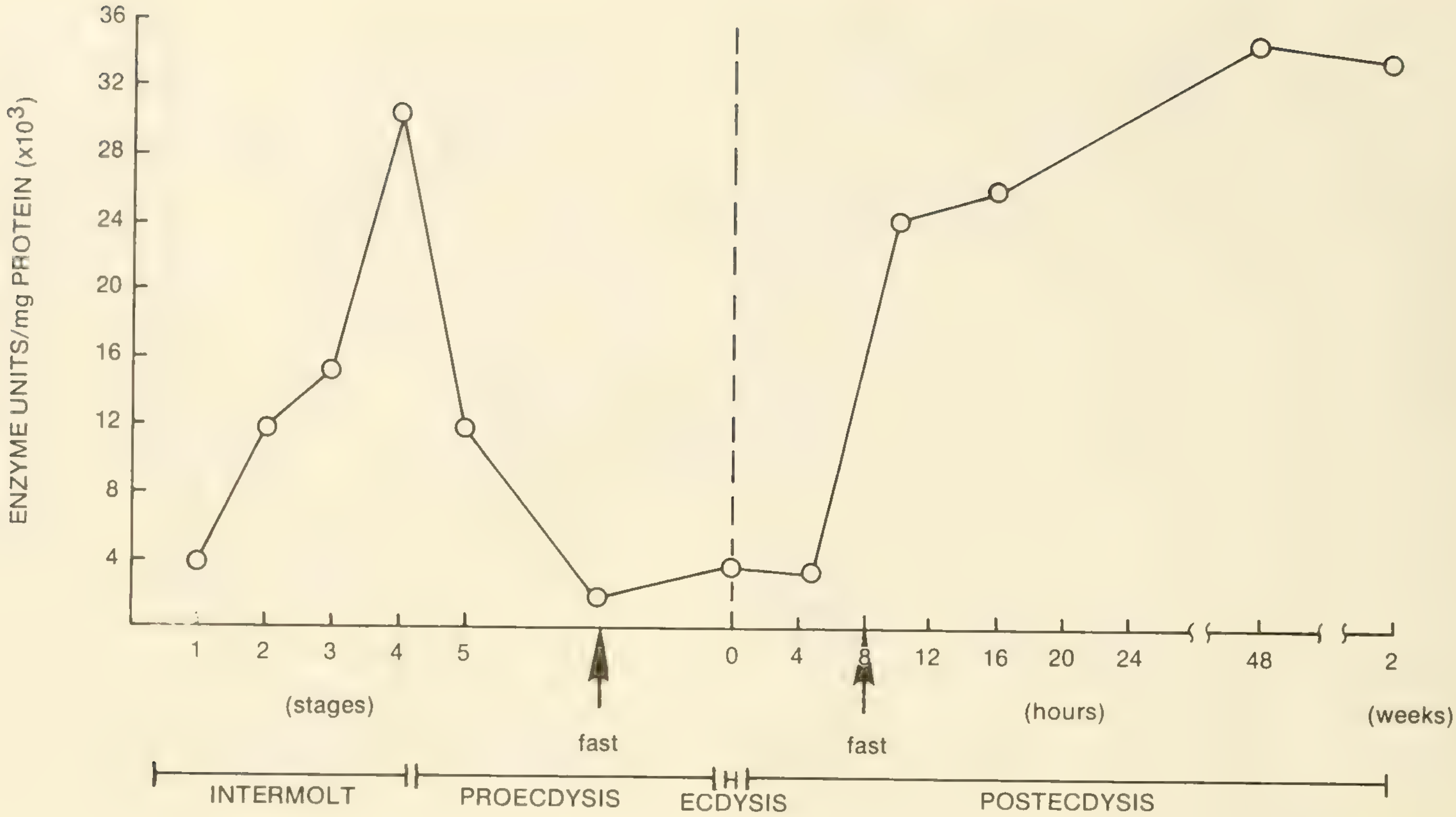

Figure 13.—Enzyme activity of blue crab during molting.

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Pollutant Responses in Marine Animals (PRIMA)

Pollutant Responses in Marine Animals (PRIMA) was initiated in March 1978 in the Environmental Quality Program. It coordinates several of the previous Biological Effects Program efforts with new projects and focuses on the development and evaluation of a set of physiological, biochemical, and morphological criteria that can be used to assess the health of marine animals. Specifically, it will determine how standardized concentrations of a limited number of model pollutants affect specific marine organisms. The test chemicals (benzopyrene, benzanthracene, fluoranthene, hexachlorobenzene, and pentachlorophenol) are representatives of important classes of chemicals known to be components of widely distributed marine pollutants. The test animals (blue crab, clam worm, soft-shell clam, hard-shell clam, atlantic oyster, and the winter flounder and mummichog) include representatives from four phyla. The investigators will focus on biochemical, physiological, and morphological changes that can be detected at the tissue, cellular, and subcellular level. Each of the morphological, physiological, and biochemical parameters should provide an indication of the health of an organism in terms of specific responses to toxic compounds. They should also provide information on the interaction of these different parameters.

The results of this project will establish biological indicators that can provide an early warning of pollutant stress in the marine environment. This advanced knowledge should make it possible to take corrective action before significant damage is done to marine benthic populations.

Controlled Ecosystem Pollution Experiment (CEPEX)

CEPEX is an international, cooperative, field research project designed to test the effects of chemical (pollutants) and physical variables on the structure of pelagic marine communities and the interactions between the various organisms. For this purpose large plastic enclosures (1,300 m^3 volume) are filled so that replicate intact water columns and their included populations are captured. Each enclosure is manipulated according to a specific experimental design, and the same populations are revisited for up to 90 days to determine shifts in population structure. The field site is located in Saanich Inlet, Vancouver Island, British Columbia. Table 4 lists the individual CEPEX projects.

During the 1977 field season, separate experiments measured the effect and chemical/biological transfer of mercury and a mixture of elements on and within pelagic populations. These results, and those from similar work in previous years, allow formulation of several generalizations and hypotheses. For example, all pollutants tested to date have had the same general effect on the populations studied. Despite massive mortality, organisms from microbes to zooplankton recovered at the concentration of pollutants tested, because mortality, although exceeding 50 percent, never reached 100 percent. Although bacteria were affected first, their rapid generation time (hours), the different makeup of numerous strains, and their ability to mutate allowed for a rapid recovery of heterotrophic activity. Zooplankton with relatively few species, numbers of individuals, and longer generation times (weeks to months) recovered most slowly. Phytoplankton with intermediate characteristics were intermediate in their recovery rates. Although there was no observed mortality of fish, metal concentrations in their tissues were greatly elevated and growth rates were reduced. If such effects on fish are cumulative, their recovery would have been less likely in experiments of longer duration.

In terms of population structure, short-term pollution effects differ from intermediate (and possibly long-term) effects. For example, earlier experiments (over 20 days) suggested that large centric diatoms were severely impacted. Longer term (90-day)

Table 4.—U.S. institutions, investigators, and projects in Controlled Ecosystem Pollution Experiment

Institutions	Investigators	Projects
University of Alaska, Marine Science Institute	J. J. Goering and A. Hattori	Nitrogen and Silicon Regeneration in Controlled Aquatic Ecosystems
University of California at San Diego, Institute of Marine Resources	J. R. Beers	The Role of Microzooplankton in an Environmental Effects Program
	W. H. Thomas	Effects of Pollutants on Marine Phytoplankton
	F. Azam	Role of Bacteria in Polluted Marine Ecosystems
University of Georgia, Skidaway Institute of Oceanography	D. W. Menzel	Integrated Field Studies and Operations
	H. L. Windom	Heavy Metal Variations in Natural and Polluted Ecosystems
University of Miami, Rosenstiel School of Marine and Atmospheric Science	M. R. Reeve	The Role of Zooplankton in an Environmental Effects Program
Woods Hole Oceanographic Institution	G. W. Grice	Zooplankton Population Assessment

experiments, on the other hand, showed that after 50 days, depletion of the toxicant in the water column or a change in its chemical form permitted a bloom of diatoms that was much higher than in controls. As the zooplankton population had not had time to recover from its initial decline following mercury addition, it is probable that reduced grazing pressure was the cause of the diatom bloom. These results show that there is little likelihood that laboratory experiments can predict anything but very short-term consequences even for phytoplankton.

The concentrations of mercury and copper at which effects did not differ from the control and those at which major population changes (mortality) occurred were for all practical purposes so close (between 1 and 5 $\mu g/l$ in both cases) that it is unlikely that subtle or chronic effects can be detected at the population level. This statement is strongly qualified to apply only to the time scale studied (80 days in this case) and directly contradicts laboratory results that indicate that mercury was three to six times more toxic to zooplankton than copper.

The sequence of events in phytoplankton and microzooplankton succession produced by the imposition of a pollutant stress do not appear to differ from those that occur over much longer periods of time in Saanich Inlet in response to natural changes in environmental conditions (light, nutrients, etc.). Any change in the biological, chemical, or physical characteristics of an environment obviously elicits responses from the biological community. Most commonly, such changes cause shifts in species diversity. The natural sequence manifests itself first at the primary producer level following a reduction of nutrient levels in the water column. These changes force the succession of phytoplankton populations from relatively large centric diatoms to small phytoplankton ($< 10\ \mu m$). This course of events is induced either by pollutant stress (copper, mercury, and oil), reduced vertical mixing in the CEPEX enclosures, or increased vertical turbulence (where phytoplankton are mixed below the compensation depth), when high nutrient concentrations are present (winter) or when nutrients are depleted (summer).

In addition to the above generalizations derived from examining the interactions of biological communities, CEPEX experiments provide valuable information on the biologically mediated behavior of trace elements. As expected, the residence time of copper in water was greater than mercury, because mercury more readily adsorbs to particulate matter. Mercury was removed from solution exponentially with time, and rates of removal were a direct function of the rate of production. More than 90 percent of the total mercury was associated with organic matter with a molecular weight $> 10{,}000$, and its toxicity was mediated by the same organic matter. Direct adsorptive uptake of mercury was rapid, and the primary mode of accumulation was by zooplankton and probably fish. Uptake from food was less important. The rate of depuration of accumulated mercury was slow. No evidence was found for biomagnification in the food chain, and no methylated mercury was found in the fish.

In another experiment, a mixture of trace metals (arsenic, antimony, chromium, copper, cadmium, lead, mercury, nickel, selenium, and zinc) was added to the enclosures. The concentration of each element was adjusted to values typical of many East Coast estuaries, but higher than those found in Saanich Inlet. Tintinnid populations disappeared, and the biomass of at least one species of larger zooplankton was reduced as was the growth of young salmon. The rate of removal of the elements from solution were in the order of zinc, mercury, lead, copper, cadmium, nickel, and arsenic. Other element concentrations before and at the conclusion of the experiment remain to be analyzed. Copper, lead, and mercury were highly enriched in samples containing surface active organic matter isolated by flotation techniques. The presence of these surface active organometallic complexes is to some extent affected by biological events.

Further efforts in CEPEX will be directed primarily to test the hypothesis that the effects of stress on biological communities, whatever their cause, follow a common sequence of events.

Volume 27 of the Bulletin of Marine Science and Volume 3 of Marine Science Communications are devoted entirely to CEPEX papers. Other papers describing the effects of mercury will appear in Volume 4 of Marine Science Communications.

Diver works on deployment of a large CEE in Saanich Inlet. Vertical shroud lines hold the 16-meter deep plastic bag in an upright position. Credit: Case Existological Laboratories

CEPEX Data

CEPEX data received during the period of this report are available from NODC as follows:

NODC Accession No.: 76–0377

Organization: CEPEX Offices, Sydney, B. C., and Skidaway Institute of Oceanography

Investigators and Grant Nos.: D. W. Menzel (SKIO) OCE73–09759; J. R. Beers (SIO) OCE73–09761; H. Windom (SKIO) OCE73–09762; R. W. Eppley (UCSD) OCE74–04838; G. W. Grice (WHOI) OCE74–05154; J. J. Goering (UAK) OCE75–03678; F. Azam (SIO) IDO73–09758; O. Holm-Hansen (SIO) OCE73–09758; R. F. Vaccaro GS–39147

Project: CEPEX Mercury experiment

Data: Reduced Data Report 1, Mercury Experiment, June 2 to July 14, 1975. Observations taken from surface to 10-m depth in ambient water and three plastic bags, in Saanich Inlet, B. C., included from 10 to 15 measurements each of temperature, salinity, sigma-t, light penetration, chlorophyll, nitrate, phosphate, silicate-nitrite, ammonia, C^{14}-productivity, solar radiation, meteorological observations, and mercury. Data received in published list form.

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Environmental Forecasting Program

The Environmental Forecasting Program focuses on projects designed to explain the large-scale, long-term behavior of the ocean and the ocean's influence on weather and climate. Experiments and studies include: Joint U.S.-U.S.S.R. Mid-Ocean Dynamics Experiment (POLYMODE); North Pacific Experiment (NORPAX); International Southern Ocean Studies (ISOS); and Climate: Long-range Investigation, Mapping, and Prediction study (CLIMAP).

MODE

Joint U.S.-U.S.S.R. Mid-Ocean Dynamics Experiment (POLYMODE)

The purpose of POLYMODE is to establish the dynamics and statistics of mesoscale motions in the ocean, their energy source, and their role in the general circulation of the ocean. POLYMODE is based on: 1) U.S.S.R. Polygon project—a continuing series of experiments investigating mesoscale phenomena in the Atlantic and Pacific Oceans and in the Arabian Sea, and 2) Mid-Ocean Dynamics Experiment (MODE-I) of the United States and the United Kingdom. A Joint U.S.-U.S.S.R. POLYMODE Organizing Committee, established under the Agreement between the Governments of the United States and the U.S.S.R. on Cooperation in Studies of the World Ocean, directs the POLYMODE experiment. The UNESCO/Intergovernmental Oceanographic Commission's Scientific Committee on Oceanographic Research (SCOR) Working Group 34 has invited other countries to participate in POLYMODE.

The *IDOE Progress Report Volume 5* gives the overall description of the U.S. POLYMODE effort. Figure 14 summarizes the location of North Atlantic measurements that have been made as part of POLYMODE. Figure 15 is a calender for POLYMODE activities. *POLYMODE News No. 39* provides an up-to-date description of U.S. activities, and is available from the POLYMODE Office, 54–1417, M.I.T., Cambridge, MA 02139. This report notes the completion of the MODE-I project, describes SOFAR float development and Soviet POLYMODE activities, and summarizes other international POLYMODE activities.

The IDOE Section and the Office of Naval Research jointly sponsor U.S. participation in POLYMODE. Table 5 lists POLYMODE projects.

Completion of MODE-I

With the publication of the article, "The Mid-Ocean Dynamics Experiment," (*Deep-Sea Research,* in press) and the *Atlas of the Mid-Ocean Dynamics Experiment (MODE-I)* (Massachusetts Institute of Technology), the MODE-I experiment is completed. All MODE-I data have been sent to NODC and are available on request. The following are scientific conclusions of MODE-I:

Midocean eddies are part of an energetic and structured variability field, which is superimposed on the weaker gyre-scale mean circulation. Identifiable closed eddies are part of a continuum of scales up to gyre width in length and $(\text{days})^{-1}$ in frequency. This variability is present in one form or another in all the oceans.

In the western North Atlantic, there is persistent eddy variability with characteristic scales of 50 days and 70 km, in which currents are horizontally nearly isotropic. Vertical scales are on the order of the depth of water and observed to be principally lowest mode over flat bottoms and highest mode over rough topography. Kinetic energy levels are up to several orders of magnitude above the mean and can vary markedly on the eddy (x2), the subgyre (x5), and gyre (x100) scale. Kinetic energy levels at 1,500 m over rough terrain appear to be diminished compared to those over nearby flat abyssal plains.

The intensity of eddy-and mean-flow kinetic energy increases markedly northward of the MODE-I area toward the Gulf Stream, and to a lesser extent southward from the MODE-I area toward the North Equatorial Current. The Gulf Stream possesses several intense varieties of variability on the eddy scale. Because the eddy and current fields are so intense in that region, the Gulf Stream (and possibly other free boundary currents in the gyre) is probably a source region for the variability. Numerical and analytical models support this conjecture and provide instability and radiative mechanisms to generate eddy variability, as well as details of the energy and scale transformation processes. Although all indicators implicate the boundary currents as at least one source of eddy energy, no conclusive field evidence has been shown. Wind has been shown to be a plausible and large potential source of eddy energy.

Mechanisms of eddy-internal wave interaction have been devised as eddy energy sinks. Large-scale numerical models suggest that bottom dissipation is responsible for absorbing eddy energy, and process models provide various mechanisms for cascading of eddy energy to smaller scales. The issue of eddy energy dissipation remains equivocal.

Deep-eddy momentum transports seem to vary directly in absolute magnitude with the mean, large-scale flows north and east of the MODE-I area. The data are insufficient to resolve cause and effect of this mean flow and eddy momentum transport relationship. Deep-eddy heat transports appear inadequate to account for the poleward climatological heat flux, but surface

layer transports induced by eddy driving from below seem to be of the right magnitude and direction.

MODE-I provided conclusive evidence for the existence of midocean eddies and a four-dimensional densely sampled data case history for analysis. As a direct result, successor and predecessor experiments will be interpreted with confidence in the context of a mesoscale eddy field.

SOFAR Floats for POLYMODE

One of the most successful instruments used in the MODE-I experiment was the SOFAR float. SOFAR floats are neutrally buoyant and can be adjusted to depths from 700 m to 2,000 m. They are carried along by ocean currents and emit regular acoustic signals. The acoustic signals are "trapped" in the SOFAR channel and propagate over ranges greater than 1,000 km. The time of arrival of the acoustic signal is detected at shore-based listening stations and is used to fix the position of the float. The MODE-I float tracks (see *IDOE Progress Report Volume 3,* fig. 12, page 13), referred to as the "spaghetti diagram" by MODE scientists, qualitatively explain a great deal about the nature of oceanic flows—a seemingly disorganized westward meandering with intermittent high-velocity bursts.

Some major modifications were made to the MODE-I floats for the POLYMODE experiment. To track more floats at greater ranges, the signaling system was changed to a chirped, frequency-modulated signal: every 8 hours the float transmits an 80-second signal in which the frequency is swept upward about 1.5 Hz. Floats are identified by different frequencies and their time of signaling. Ten frequency channels are used, between 230 and 270 Hz, with about 4.7 Hz between channels. In a given frequency band, each float is assigned a time window of 10 minutes width for signal transmission.

POLYMODE floats have been designed to stay at a constant pressure (the MODE-I floats sank slowly, about 0.5 m per day, owing to inelastic creep in the aluminum float housing) and to telemeter temperature and pressure data. Data telemetry is by pulse delay modulation. Once every 24 hours, 2 to 10 minutes after the regular signal, an auxiliary signal is transmitted. The period between the two signals is a function of the data being telemetered. For a float at 2,000 dB, the pressure range is ±200 dB, the resolution, ±0.4 dB; and the temperature range is 3.2° to 4.2°C, the resolution, ±0.002°C. Two-day averages

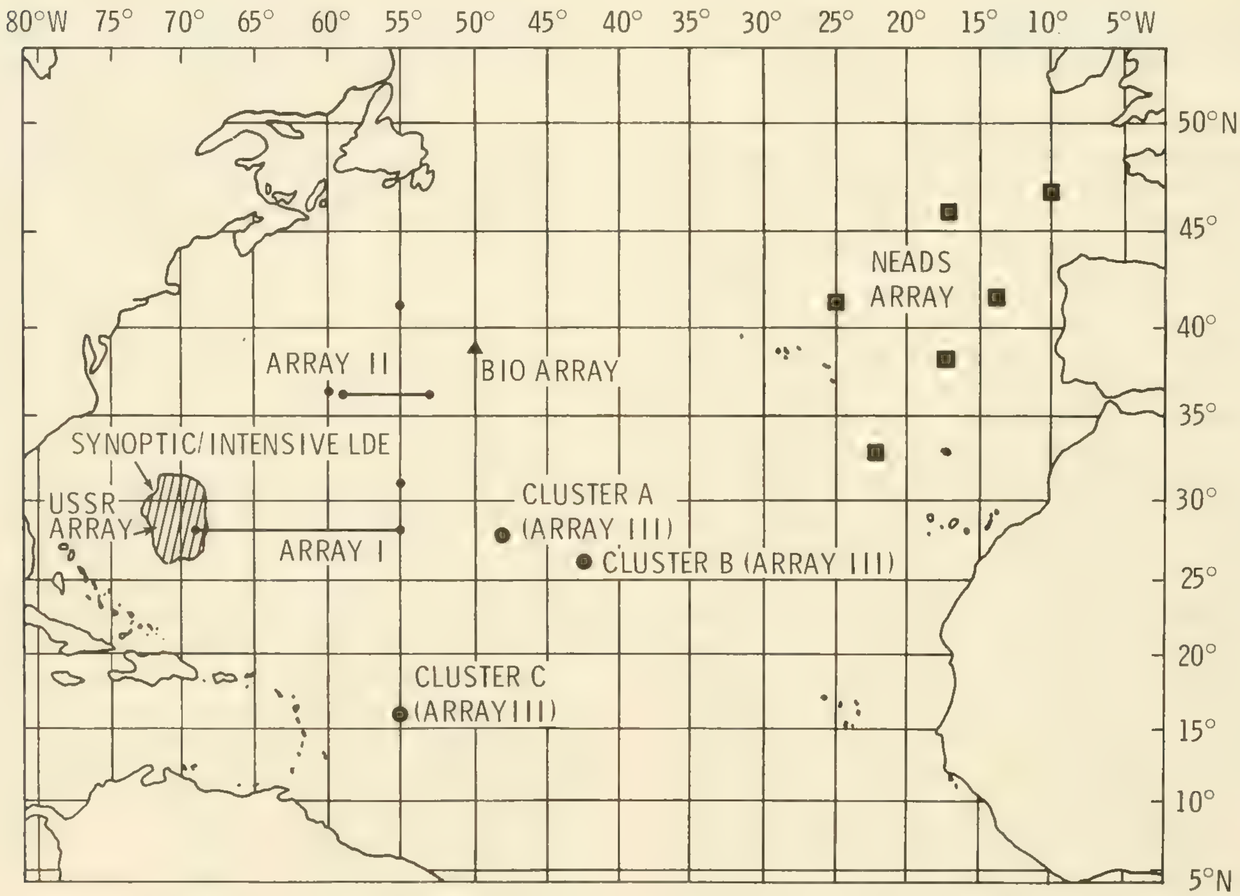

Figure 14.—Geographical distribution of field work in POLYMODE.

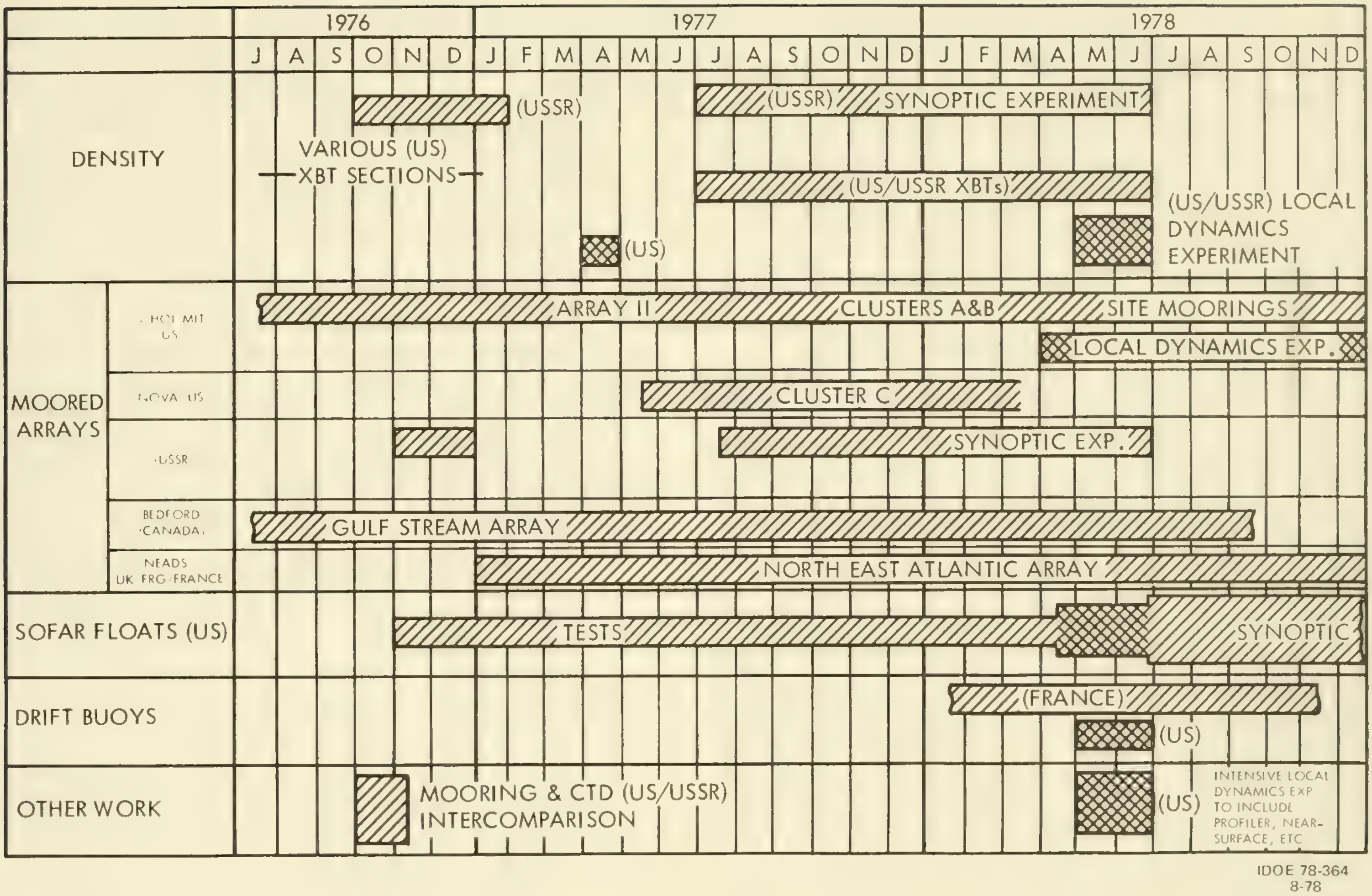

Figure 15.—Calendar of overall POLYMODE field program.

of temperature and pressure are transmitted on alternate days.

To control the float depth, a block of anode quality zinc is mounted externally in the seawater. This anode can be electrically connected to the main aluminum housing via a switch controlled by the pressure measurement and averaging circuit. When the circuit is open, the electrochemical couple is inactive; when the circuit is closed, a small saltwater battery is formed, zinc goes into solution in the seawater, and the float rises about 2 m per day.

POLYMODE floats are also being built with a relocation and recovery subsystem for ship retrieval at sea. This is a specially designed, multiple-address system using 1420-Hz phase encoded data transmitted from the ship to the float and received via the float's low-frequency transducers. Float reply is via the normal low-frequency signal. A recovery command causes a 7-kg external ballast weight to jettison and initiates a special fast pressure telemetry cycle to verify the weight release and aid recovery.

Since 1975, 28 POLYMODE-type floats have been built and used at sea. The floats have evolved from a prototype stage to a more or less fixed and well-proven design that is suitable for commercial fabrication. From 1975 to 1978, the following problems occurred:

1) Serious damage to the floats resulted from several handling incidents. Special handling equipment was developed to avoid damage.

2) Electronic equipment failures occurred shortly after floats were launched. Thorough burn-in of the electronic equipment was found to be important. Adequate time must be allowed between fabrication and deployment for burn-in of electronic components.

3) Floats built commercially differed slightly from those built in the lab. Careful and uniform test procedures for equipment are essential to ensure an effective transition from a research activity to a routine operation.

Table 5.—U.S. institutions, investigators, and projects in POLYMODE

Institutions	Investigators	Projects
University of California, San Diego	R. Salmon and M. C. Hendershott	Statistical Properties of Quasi-Geostrophic Ocean Flow Models
	R. Davis	Upper Ocean Current Measurements
	R. E. Lange	Measurements of Temperature and Salinity Microstructure
Harvard University	A. R. Robinson	Analytical and Numerical Studies of Mesoscale Motions
Massachusetts Institute of Technology	G. Flierl	Theoretical Studies of Mesoscale Ocean Dynamics
	C. Frankignoul and H. Stommel	Mesoscale Forcing of the Upper Layer of the Ocean
	R. Heinmiller and H. Stommel	Coordination, Planning, Workshops, Communications, and Administration
	V. Lee and H. Stommel	MODE–1 Atlas
	L. Regier	Upper Ocean Soundings of Current Velocity
	C. Wunsch	Moored Arrays for Study of Low-Frequency Oceanic Variability
University of Miami	H. Perkins, J. Van Leer, and K. Leaman	Upper Ocean Current Measurements
U.S. Naval Academy	L. Dantzler	An Evaluation of Mesoscale Oceanic Eddy Statistics From Both Historical and Ship-of-Opportunity XBT Data
Naval Research Laboratory	J. Dugan	POLYMODE Synoptic Surveys
Nova University	P. Bedard	A Moored Array for Study of Low-Frequency Oceanic Variability in the Atlantic North Equatorial Current (Array 3, Cluster C)
Oregon State University	P. Niiler	A Moored Array for Study of Low-Frequency Oceanic Variability in the Atlantic North Equatorial Current (Array 3, Cluster C)
University of Rhode Island	H. T. Rossby	A Synoptic Study of Barotropic and Baroclinic Eddies in the Ocean
	R. Watts	A Study of Small-Scale, High-Frequency Displacements of the Main Thermocline in the Region of the Western Sargasso Sea
University of Washington	B. Taft, J. C. McWilliams, and C. Ebbesmeyer	Hydrography Program for the Local Dynamics Experiment
	M. Gregg	Oceanic Microstructure Measurements
Woods Hole Oceanographic Institution	N. P. Fofonoff	Moored Arrays for Study of Low-Frequency Oceanic Variability in the Region of the Mid-Atlantic Ridge (Array 3, Clusters A and B)
	N. P. Fofonoff and W. J. Schmitz	An Intercomparison of U.S. and U.S.S.R. Moorings, Current Meters, and Conductivity-Temperature-Depth Instruments.
	J. Luyten	Moored Current Measurements for the Local Dynamics Experiment
	J. McCullough	Upper Ocean Current Measurements
	G. Metcalf	A Coordinated Expendable Bathythermograph (XBT) Program
	T. Sanford	A Study of the Vertical Structure and Energy of Midocean Eddies Using Electromagnetic and Doppler Profilers

Table 5.—U.S. institutions, investigators, and projects in POLYMODE (Cont.)

Institutions	Investigators	Projects
	D. C. Webb	Float Project
	F. Webster	Newsletter
Yale University	R. Hall	Nonlinear Effects on the Scattering of Quasi-Geostrophic Waves

Figure 16 shows an example of the position track and temperature-pressure telemetry for a POLYMODE float.

To free SOFAR floats from the constraint of being in the listening range of shore stations, four self-contained, moored, float-tracking stations, referred to as autonomous listening stations (ALS), are being built and tested as part of POLYMODE. The POLYMODE float project is designed to rely on shore-based receiving stations and will provide a controlled test of ALS performance.

To provide an acceptable deployment duration (6-12 months), ALS must preprocess the acoustic signals it receives and only record those that appear to be from floats. The processing algorithm currently being used reduces the data by a factor of 62.5 and gives a duration of 2 frequency channel years, or about 100 float years. The battery life is at least 18 months.

The prototype ALS was deployed for 8 days in January 1977 on the slope of San Salvador Island near the depth of the sound channel axis. This test produced a short but encouraging record of detected float signals. The instrument was then deployed off Plantagenet Bank south of Bermuda from April to October 1977 and provided a data base of more than 9,000 signals for performance analysis. Results indicate that out to a range of 1,300 km there is negligible reduction in the ALS performance owing to data compression procedures.

Soviet Measurements

The U.S.S.R. POLYMODE field program began in June 1977 and will extend to August 1978. The strategy of the Soviet program is to investigate the kinematics and dynamics of the mesoscale eddies by repetitive synoptic surveys in a block of the ocean encompassing several eddies. Simultaneously, a moored current meter array will determine eddy characteristics (scales and energy levels) within the region, and, if records are sufficiently long, eddy statistics. Nineteen surface moorings have been deployed, and these will be instrumented at five levels to a maximum subsurface depth of 1,500 m. These moorings are deployed in a multiantenna array (fig. 17) that is centered on 29°N, 70°W. The array consists of five combined nonsymetric cross-shaped clusters with elements arranged in a pattern similar to that planned for the clusters of U.S. Array III. Current meters and temperature recorders were placed at 100-, 400-, 700-, 1,400-, and (on some moorings) 4,000-m levels. Temperature is measured at 100 and 700 m.

The Soviets are carrying out 10 to 12 synoptic density surveys. XBTs, supplied by the United States, will be used along with Soviet CTDs. Each survey will require about 20 days, and will cover an area about 500 km in diameter. Spacing between XBT soundings will be about 30 km. All density data are reported by radio using the Integrated Global Ocean Station System (IGOSS). NOAA's National Weather Service constructs charts of the data and retransmits these charts to Soviet and American ships via facsimile. (See fig. 18.)

Soviet measurements are closely integrated with United States efforts as part of the Local Dynamics Experiment. A United States current meter array (10 moorings, 31 current meters,

Loading SOFAR floats for sea.

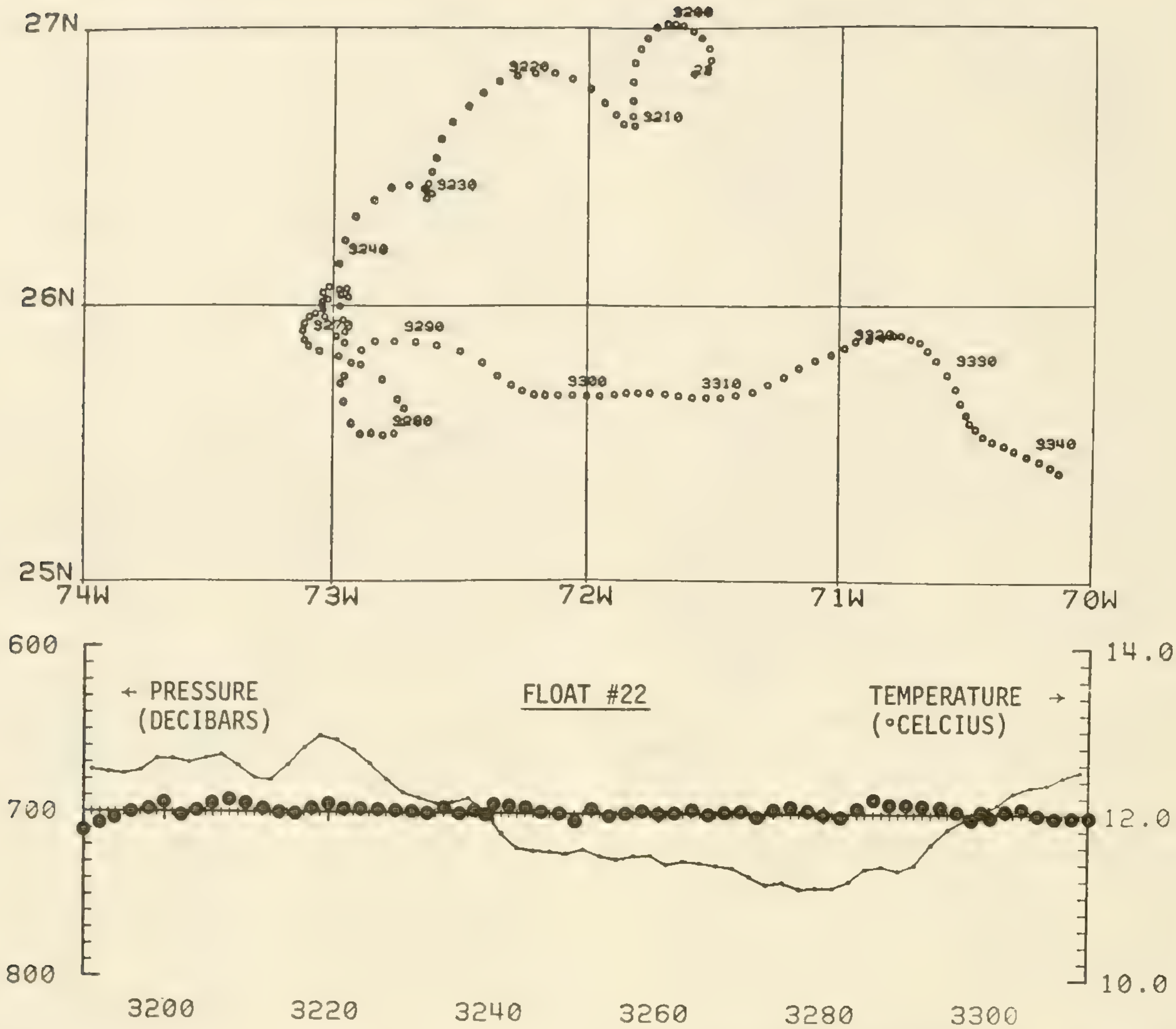

Figure 16.—Typical float position track and telemetry. Latitude and longitude as a function of time are shown in the upper part. Temperature and pressure vs. time are shown at the bottom. The continuous line represents temperature, the unconnected points present pressure.

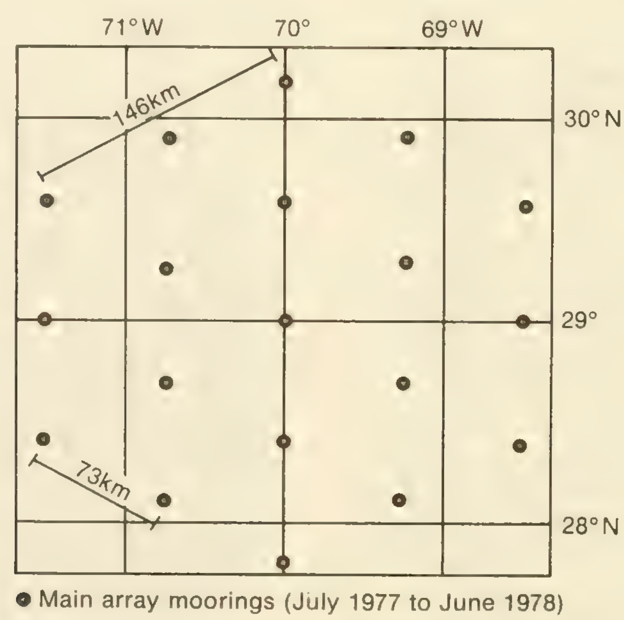

Figure 17.—U.S.S.R. synoptic mooring array of 19 moorings in a multi-antenna array set in July 1977 in the Hatteras Plain.

19 temperature-pressure recorders) will be set at about the same longitude as the Soviet current meter array, but about 200 km to the north in May 1978. The region of density surveys and SOFAR float tracking will encompass both current meter arrays. Results will be summarized in atlases, joint papers, and monographs.

Other Programs

A number of mesoscale experiments, which have common scientific objectives with POLYMODE, are scheduled for the North Atlantic Ocean in calendar years 1977 through 1979.

North East Atlantic Dynamics Study (NEADS). Six single subsurface moorings were set in January 1977, in the Eastern Basin of the Atlantic by scientists of France, West Germany, and United Kingdom. These moorings were instrumented with current meters, temperature, and some pressure recorders at 600, 1,500, 3,000, and 5,000 m above the sea floor. They will be maintained for up to 2 years in the northern half of the eastern North Atlantic basin. The mooring sites are widely spread and generally far removed from large topographic features to gain geographical and statistical information about energy levels, time scales, and vertical structure of currents, and to evaluate some Reynolds stresses. The moorings were recovered and redeployed in December 1977.

The Bedford Institute Array. To study the highly variable currents under the Gulf Stream, the Bedford Institute of Oceanography in Canada maintained three subsurface moorings in a cluster under the axis of the Gulf Stream at 40°N, 56°W from December 1975 to May 1977. The moorings were anchored at a depth of nearly 5,200 m and had temperature-equipped Aanderaa current meters at 4,000 and 4,760 m.

In May 1977, a new three-mooring array was deployed near 38°N, 50°W. The array will be maintained until late 1978. Each mooring will carry instruments at 4,000 and 4,750 m in about 5,400 m deep water.

Surface Drifters. The Laboratoire d'Oceanographie Physique of France proposes to deploy about 30 drogued surface drifters in a cluster to describe mesoscale features in the surface layer. The drifters provide a measure of currents in the upper 10 m and would be equipped with thermistor chains extending below the seasonal thermocline. The data from these buoys would be integrated with very high resolution satellite radiometric surface-temperature measurements. The buoys will be deployed in 1978 in the eastern basin of the Atlantic in coordination with the NEADS moorings.

MODE and POLYMODE Data

MODE and POLYMODE data received during the period of this report are available from NODC as follows:

NODC Accession No.: 78–0028
Organization: WHOI
Investigators: K. Bradley (WHOI), C. Wunsch (MIT), T. Rossby (URI)
Grant No.: OCE75–03998, IDO75–18930, OCE75–03962
Project: POLYMODE Array 1
Data: 7 moorings, 27 current meters at 500, 1,000, 2,000, and 4,000 m depths, 20 temperature and pressure sensors, from 28°N 70°W to 55°W and 60°W, from 28°N to 34°N, July 1974 to May 1975. Data received at NODC on two reels of magnetic tape.

Setting current meters aboard the U.S.S.R. RV BUGAEV, July 1977.

NODC Accession No.: 78–0022
Organization: University of Rhode Island/Woods Hole Oceanographic Institution
Investigator(s): P. Richardson (WHOI), T. Rossby (URI)
Grant No.: OCE75–08765, NSF/OCE75–18930
Project: POLYMODE Eddies
Data: 11 CTD stations in the western North Atlantic taken aboard RV TRIDENT, cruise TR–175, November 20 to December 10, 1975. Data received on magnetic tape in GATE format.

NODC Accession No.: 77–0831
Organization: Woods Hole Oceanographic Institution
Investigator: Keith Bradley (WHOI)
Grant No.: OCE75–03962
Project: POLYMODE Eddies
Data: 13 CTD stations in the western North Atlantic taken aboard RV CHAIN, cruise CH–129, December 3 to 23, 1975. Data received on magnetic tape in GATE format.

NODC Accession No.: 77–0831
Organization: Woods Hole Oceanographic Institution
Investigator: P. Richardson (WHOI)
Grant No.: OCE75–08765

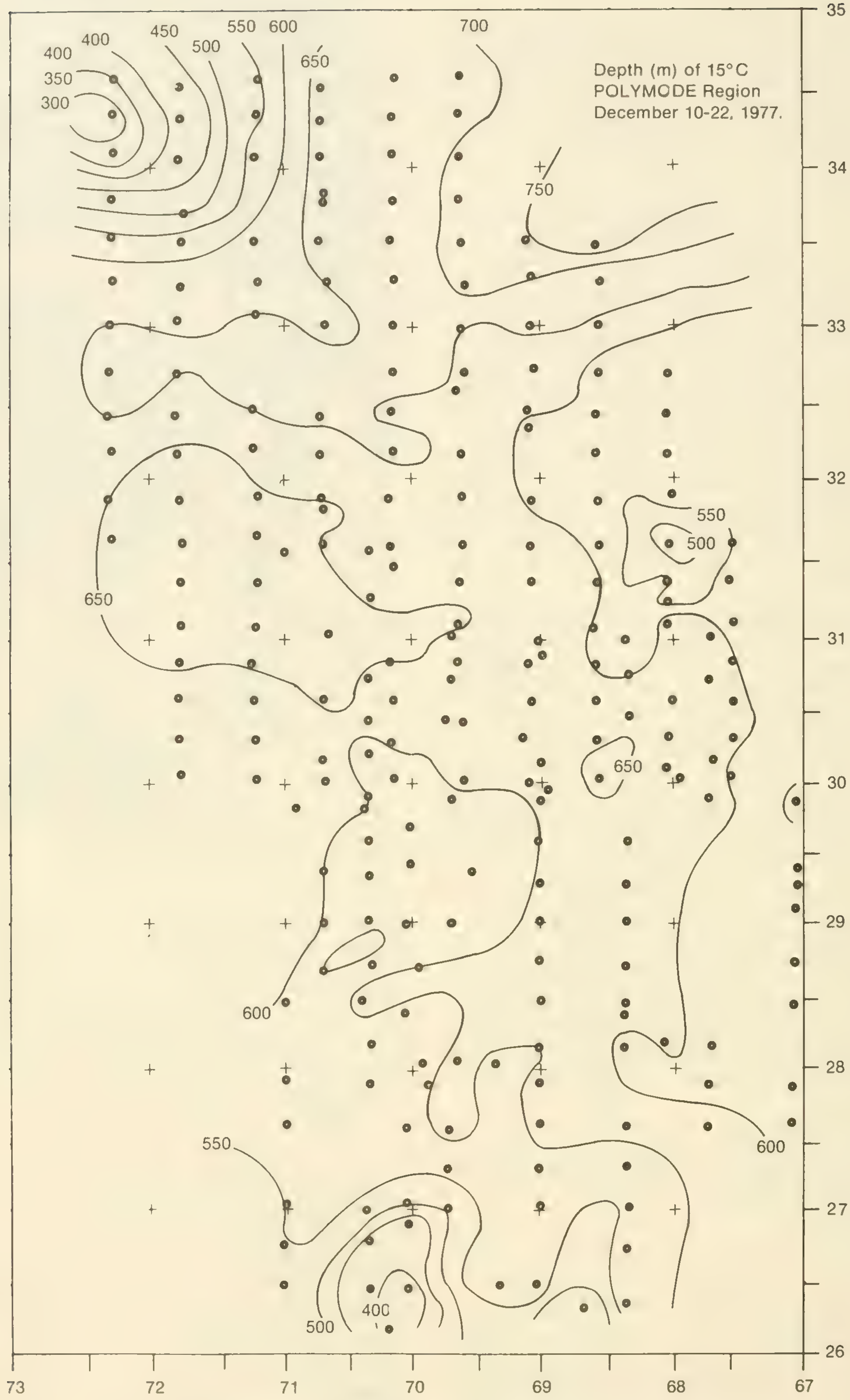

Figure 18.—Density data chart of NOAA's National Weather Service for POLYMODE Region.

Project: POLYMODE Rings
Data: 24 CTD stations in the western North Atlantic taken aboard RV KNORR, Cruise K–62, in November 1976. Data received on magnetic tape in GATE format.

NODC Accession No.: 77–0831
Organization: Woods Hole Oceanographic Institution
Investigator: P. Richardson (WHOI), N. Fofonoff (WHOI)
Grant No.: OCE75–08765, NSF/OCE75–03962
Project: POLYMODE Rings
Data: 15 CTD stations in the western North Atlantic, taken aboard RV KNORR, Cruise K–60, October 3 to 19, 1976. Data received on magnetic tape in GATE format.

NODC Accession No.: 77–0831
Organization: Woods Hole Oceanographic Institution
Investigator: G. Seaver (WHOI) (MIT)
Grant No.: IDO75–04215
Project: POLYMODE Rings
Data: 82 CTD stations in the western North Atlantic taken aboard RV CHAIN cruise CH–118, January 22 to February 2, 1975. Data received on magnetic tape in GATE format.

NODC Accession No.: 77–0569
Organization: Massachusetts Institute of Technology
Investigator: C. Wunsch (MIT)
Grant No.: IDO75–03998
Project: POLYMODE Moorings
Data: 750,000 temperature and pressure values in the POLYMODE area from December 7, 1975, to January 3, 1977, submitted on NODC-compatible magnetic tape.

NODC Accession No.: 77–0552

Ship/Cruises: TRIDENT/TR–133, TR–136, 5/9/73–6/1/73, 3/12/73–4/4/73
Investigators/Grant Nos.: R. Scarlett (MIT)/GX–31340
D. Hanson (AOML)/AG–385
Data: 99 CTDs on magnetic tape (GATE format);

Ship/Cruise: HUNT/73 leg 3, May 1973
Investigator/Grant No.: W. Brown (SIO)/GX–31340
Ship/Cruise: HUNT/73 leg 3.5, May to June 1973
Investigator/Grant No.: D. Moore (MIT)/GX–29034
Ship/Cruise: HUNT/73 leg 5, June to July 1973
Investigator/Grant No.: D. Moore (MIT)/GX–29034
Data: 315 CTDs on magnetic tape in GATE format;

Ship/Cruise: RESEARCHER/73–1 leg 1, March 1973
Investigator/Grant: A. Leetmaa (AOML)/AG–385
Data: 37 CTDs on magnetic tape in GATE format;

Ship/Cruise: RESEARCHER/73–1 leg 2, April 1973
Investigator/Grant: A. Leetmaa (AOML)/AG–385
Data: 52 CTDs on magnetic tape in GATE format;

Ship/Cruise: RESEARCHER/73–1 leg 3, May 1973
Investigator/Grant: D. Hanson (AOML)/AG–385
Data: 74 CTDs on magnetic tape in GATE format;

Ship/Cruise: RESEARCHER/73–1 leg 4, June 1973
Investigators/Grant: D. Hanson (AOML)/AG–385, J. Crease (NIO)
Data: 72 CTDs on magnetic tape in GATE format.

NODC Accession No.: 77–0551
Organization: Woods Hole Oceanographic Institution
Investigators: N. P. Fofonoff (WHOI), W. J. Schmitz (WHOI)
Grant No.: IDO75–21469
Project: Soviet-American CTD Intercalibration
Data: 7 CTDs in POLYMODE area taken aboard RV VERNADSKIY cruise 14, October 17 to 21, 1976. Data submitted on magnetic tape in GATE format.

NODC Accession No.: 77–0437
Ship/Cruise: CHAIN/CH–112 legs 1, 2, 3/6/73–4/20/73
Investigator/Grant No.: D. Hanson (AOML)/AG–385
R. Heinmiller (WHOI)/GX–29054
Data: 152 CTDs on magnetic tape in GATE format.

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Heinmiller, R. H.
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1977a. Trans-Atlantic XBT section by the Soviet Research Vessel AKADEMIC VERNADSKY. October 1976. XBT Tech. Rpt. 77–1, POLYMODE XBT GROUP, Woods Hole Oceanogr. Inst., 7 p.
1977b. XBT survey of two mesoscale features in the NW North Atlantic by the Soviet Research Ship AKADEMIK VERNADSKY October 1976. XBT Tech. Rpt. 77–2, POLYMODE XBT GROUP Woods Hole Oceanogr. Inst., 10 p.

Rhines, P. B. (editor).
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western North Atlantic. Rev. Geophys. Space Physics 15:385–420.

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North Pacific Experiment (NORPAX)

The long-term objective of NORPAX is to understand fluctuations in the upper layers of the North Pacific Ocean and their relation to the overlying and adjoining atmosphere. These fluctuations have time scales of months to years and a space scale in excess of 1,000 km. Achievement of this goal should lead to improved prediction of weather and climate for the northeast Pacific Ocean and North America. NORPAX is working to attain its long-range objective through analysis of historical data, experiments to identify and understand important processes, monitoring of low-frequency fluctuations, and integration of observations with theoretical and numerical studies.

NORPAX is jointly sponsored by the IDOE section and the Office of Naval Research. The principal investigators form the nucleus of NORPAX (table 6). They annually elect an executive committee that oversees the program, formulates plans and policy, coordinates activities, and represents NORPAX in dealings with the granting agencies and the scientific community. The five members of the executive committee select a chairman, who is assisted by the program administrator.

Most principal investigators belong to at least one of the various groups and task forces formed within the program. These groups are related to certain scientific problem areas (Climate Studies), to specific experiments (Anomaly Dynamics Study), or to important organizational tasks (Satellite Data Evaluation Panel). Membership in these groups is voluntary and by self-appointment; scientists who are not NORPAX investigators, but who are willing to contribute to the program, may also be members of these groups.

Climate Studies

The Climate Studies seek to understand long-period, large-scale changes in temperature and circulation in the North Pacific and to relate these changes to variations in atmospheric circulation. As such, these studies are basic to NORPAX in general and to specific programs in NORPAX such as the Anomaly Dynamics Study and the Equatorial Program. This year, it has been proposed that a specific Climate Program be formed within NORPAX, not to dilute the other programs but to encourage greater interaction and coordination among all programs in support of the overall climate-related objectives of NORPAX as shown in figure 19.

In particular, the purpose of a NORPAX Climate Program is to focus the data and experience on large-scale air-sea interaction, developed within NORPAX, on the role of the ocean in seasonal and interannual climate variability. This program will help identify the need for:

1) procurement and processing of new climatic data sets,

2) design of new statistical and phenomenonological studies of air-sea interaction using these data,

3) formulation of new empirical hypotheses and statistical models of regional and interannual climatic variability on the basis of these studies, and

4) design and application of new dynamic models of climate to test these hypotheses.

Obtaining new data and retrieving existing data from other sources are continuing processes. Much of the data is obtained through ship-of-opportunity programs coordinated both by individual investigators and by the Fleet Numerical Weather Central.

A cooperative program with the Max Planck Institute of Hamburg has resulted in a preliminary form of a generalized approach to linear multivariate prediction. This technique allows a quantitative estimate of the artificial predictability associated with a given hindcast and has been used to predict the strength of the Intertropical Convergence Zone over most of the central Pacific Ocean for 6 months in advance and sea-surface temperature in the equatorial central Pacific to 8 months in advance. Both results are significant at the 95 percent confidence level.

Anomaly Dynamics Study

The objective of the Anomaly Dynamics Study (ADS) is to explain the origin of the large heat storage anomalies that are observed in the surface layer of the Pacific Ocean. One important part of the program is regular monitoring, by aircraft and merchant ships, of the thermal structure of the ocean's upper layer in the region 30°N to 50°N, 140°W to 180°W.

Two ADS reports have been issued, ADS–1 in October 1977 and ADS–2 in November 1977, and a third is in preparation. These contain contour maps of the following monthly mean data: Fleet Numerical Weather Central air temperature, windspeed, wind direction, surface-vapor pressure, and 700-mb heights; NORPAX-calculated wind stress, wind-stress curl, wind-shear velocity cubed, sensible heat flux, and latent heat flux; objectively analyzed TRANSPAC temperatures at discrete depths, and monthly drifter buoy displacement vectors. The ADS timetable is indicated in figure 20.

One observation of interest was the tendency for deep (300m) temperature anomalies to travel westward at 20cm/s in the TRANSPAC region as shown in figure 21.

Another observation is the more active response in the western North Pacific as opposed to the eastern region as seen in figure 22.

Table 6.—U.S. institutions, investigators, and projects in NORPAX

Institutions	Investigators	Projects
University of Alaska	T. C. Royer	Circulation and Heat Content Fluctuations in the Subpolar Gyre and Their Atmospheric Coupling
University of British Columbia	M. Miyake	AXBT Measurements in the North Pacific Ocean
California Institute of Technology, Jet Propulsion Laboratory	M. T. Chahine	Remote Sounding of Temperature of the Oceanic Surface in Cloudy Atmosphere
University of California, San Diego, Scripps Institution of Oceanography	R. L. Bernstein and W. B. White	Low-Frequency Baroclinic Responses of the North Pacific Current to Interannual Variability in the Westerly Winds
	N. E. Clark	Interannual Variability of Large-Scale Heat Exchange Across the Air-Sea Interface in the Eastern North Pacific Ocean
	R. E. Davis	Upper Ocean Dynamics
	R. E. Davis and R. Knox	Monitoring Equatorial Currents in the Central Pacific
	C. A. Friehe	Surface Meteorological Observations from Transpacific Merchant Ship
	G. J. McNally	North Pacific Current Study
	J. Namias	Large-Scale and Long-term Ocean Atmosphere Coupling Over the Pacific and Remote Weather and Climate Influences
	W. C. Patzert and T. P. Barnett	Aircraft Monitoring of Equatorial Currents during NORPAX Test Shuttle
	D. Cutchin and M. J. Desruisseaux	Administration
	S. Pazan	Data Program
	W. B. White, K. Hasanuma, and H. Solomon	Year-to-Year Variability in the Thermal Structure of the Subtropical Gyre of the Western North Pacific Ocean
	W. B. White and R. L. Bernstein	Hydrographic Measurements of the North Pacific Current
Center for the Environment and Man, Inc.	C. A. Jacobs	Numerical Modeling of Possible Endemic Generating Mechanisms of the North Pacific Ocean Temperature Anomalies
University of Hawaii	R. Harvey	Equatorial Current Measurements
	L. Magaard	Baroclinic Rossby Waves in the North Pacific
	J. C. Sadler	Pacific Cloudiness and Atmospheric Anomalies
	M. J. Vitousek	Line Island Monitoring
	K. Wyrtki	The Interaction of Circulation, Sea Level, Heat Storage, and Winds Over the Pacific
	K. Wyrtki and A. Bainbridge (SIO)	Oceanographic Shuttle Between Hawaii and Tahiti
NOAA/Environmental Research Laboratories	B. Bean	Aircraft Phase of the Equatorial Shuttle Experiment
NOAA/ERL Atlantic Oceanographic and Meteorological Laboratories	D. Hansen	Drifter Measurements in the North Equatorial Countercurrent
NOAA/ERL Pacific Marine Environmental Laboratory	D. Halpern	Transport of the North Equatorial Countercurrent in the Central Pacific
NOAA/National Marine Fisheries Service	J. F. T. Saur and D. R. McLain	Ships of Opportunity Time Series XBT Sections for the Eastern North Pacific Ocean
Nova University	D. Moore and J. McCreary	Equatorial Ocean Response to Seasonal Winds

Table 6.—U.S. institutions, investigators, and projects in NORPAX (Cont.)

Institutions	Investigators	Projects
U.S. Naval Oceanographic Laboratory	H. E. Hurlbert J. D. Thompson, and S. A. Piacsek	A Numerical Investigation of the Time-Dependent Circulation of the Equatorial and Eastern Pacific
USN/Fleet Numerical Weather Central	R. E. Hughes	Ships of Opportunity XBT Program
USN/Naval Postgraduate School	R. L. Haney	Numerical Simulation of the Coupled North Pacific Ocean-Atmosphere System
Oregon State University	W .L. Gates	Research on the Dynamics of the Mixed Layer and Its Role in the Oceanic General Circulation
San Diego State University	C. E. Dorman	Variability of the Oceanic Thermal Structure Between San Francisco and Hawaii
Texas A&M University	W. Emery	Computation of Density from Measurements of Thermal Structure
	A. D. Kirwan	Anomaly Dynamics Study
University of Tokyo	H. Solomon	The Role of Subpolar Western Boundary Currents in Large-scale Ocean Atmosphere Coupling in the North Pacific
University of Washington	B. A. Taft	Study of Thermocline Fluctuations of the Pacific North Equatorial Current

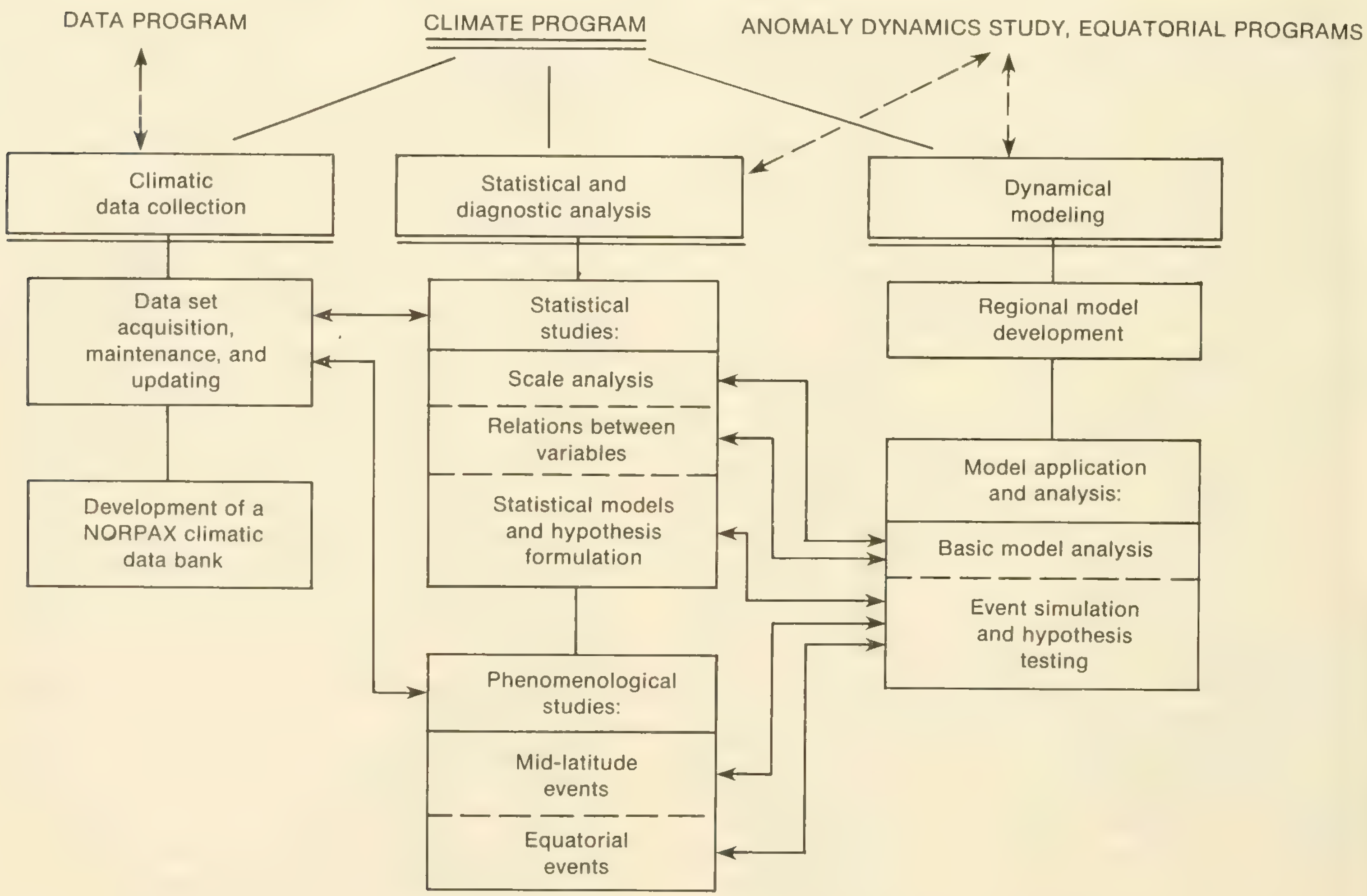

Figure 19.—Elements and activities of the NORPAX Climate Program and their principal interactions.

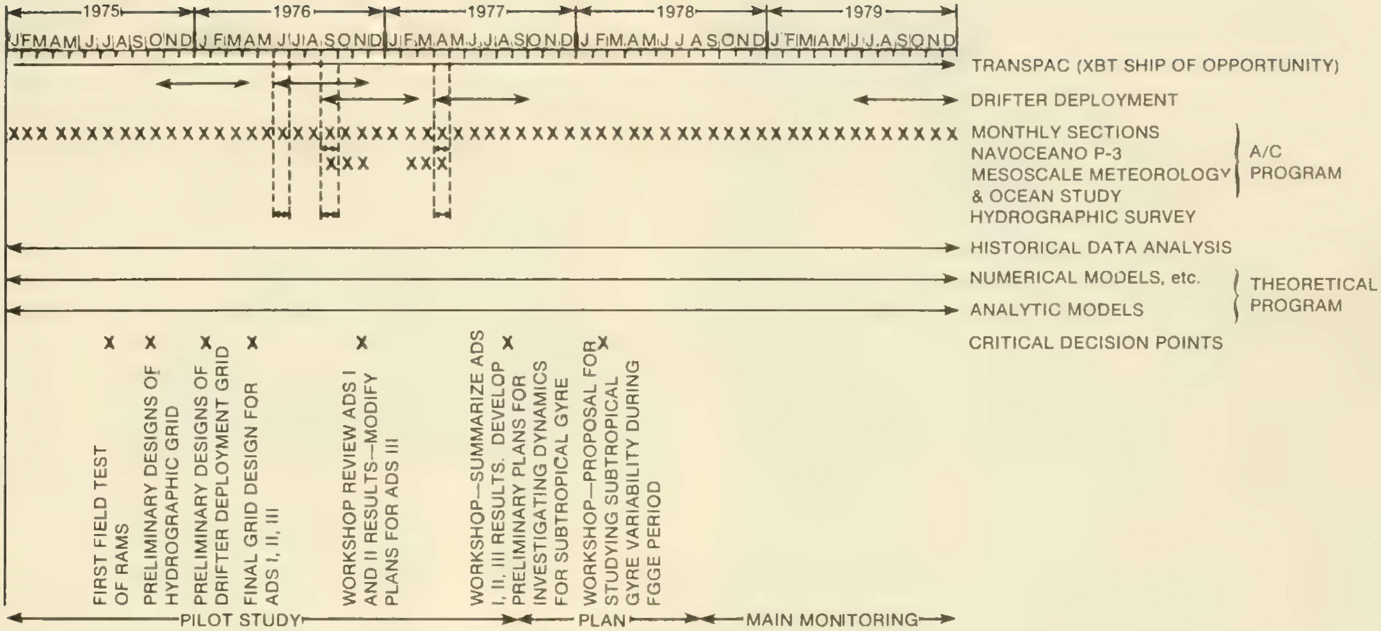

Figure 20.—Anomaly Dynamics Study—Time Phase Diagram.

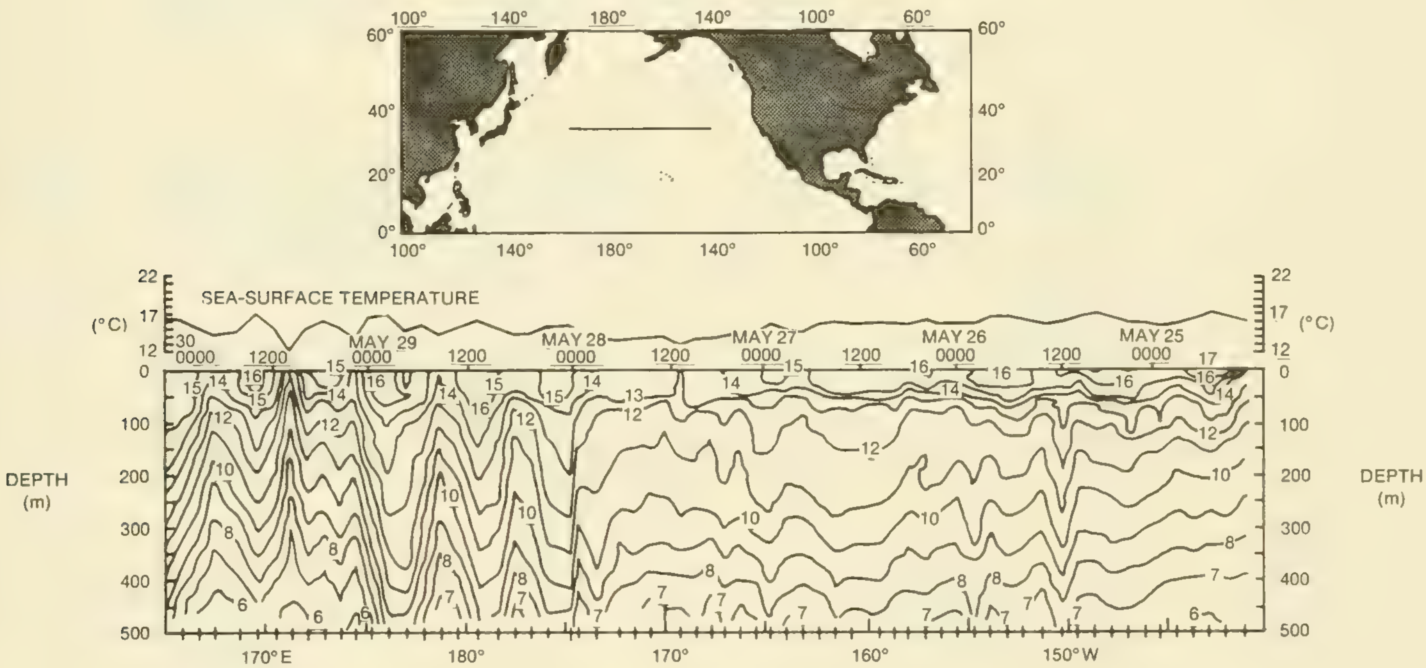

Figure 21.—TRANSPAC region temperature profile.

Equatorial Program

The overall objectives of the NORPAX Equatorial Program are to observe and explain large-scale, long-period fluctuations in the equatorial Pacific current system. This program derives its inspiration from two sources. First, oceanographers wish to understand the mechanisms by which the equatorial current system produces anomalous temperature structure, which is especially important at low latitudes, because it dramatically influences commercial fisheries and the circulation of the atmosphere. Second, oceanographers want to interact with meteorologists and climatologists during the First GARP Global Experiment (FGGE) in 1978–79. During FGGE, special aircraft, satelites, and ship observations will be made to provide wind-stress and heat-flux data of excellent quality and in un-

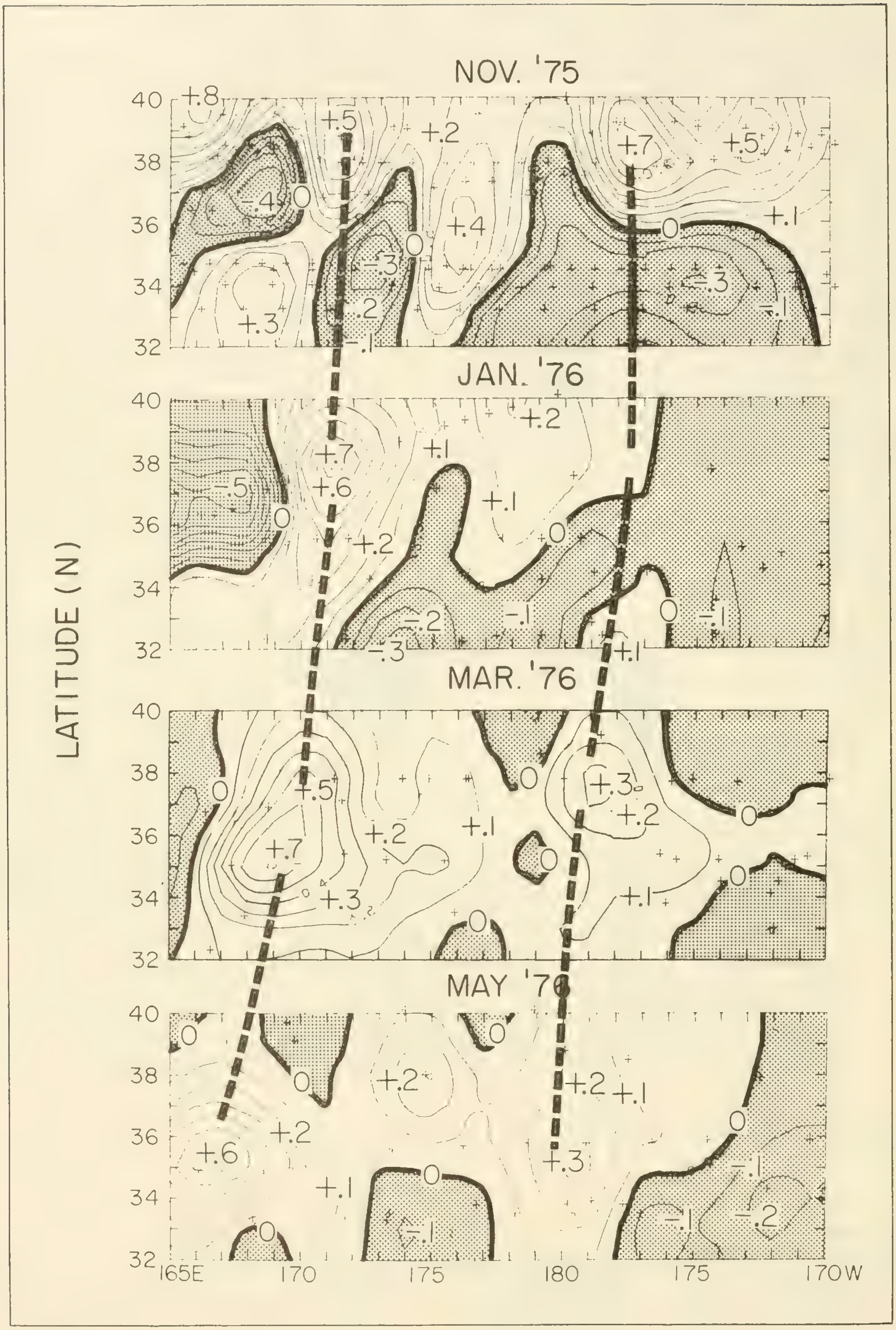

Figure 22.—Temperature anomaly at 200 m.

precedented qualities. *IDOE Progress Report, Volume 6,* contains additional information on the Equatorial Program.

The NORPAX Equatorial Program began with a 3-month test shuttle across the Equator between Honolulu, Hawaii, and Papeete, Tahiti. Measurements have been or are being made from ships, aircraft, moored instruments, drifters, and island stations as indicated in figure 23. Figure 24 shows some previous transequatorial XBT section locations. Figure 25 is an earlier profile of dynamic topography along 155°W.) For example, the first leg of the RV KANA KEOKI, which took place November 9–29, 1977, took 61 CTD profiles to 1,000 m and intermediate XBT casts; launched radiosonde balloons twice a day; deployed 11 satellite-tracked drifting buoys, 4 ocean-bottom seismometers, 2 bottom-pressure recorders, 6 bottom-current meters, and 2 surface-bottom moorings; and continuously recorded surface temperature and salinity. The purpose of the data collected during this preliminary phase is to aid in long-term equatorial planning.

NORPAX Data

NORPAX data received during the period of this report are available from NODC as follows:

NODC Accession No.: 77–0894, Reference Nos.: 52326 thru 52620

One of the 16 local inhabitants who process NORPAX data in the Line Islands.

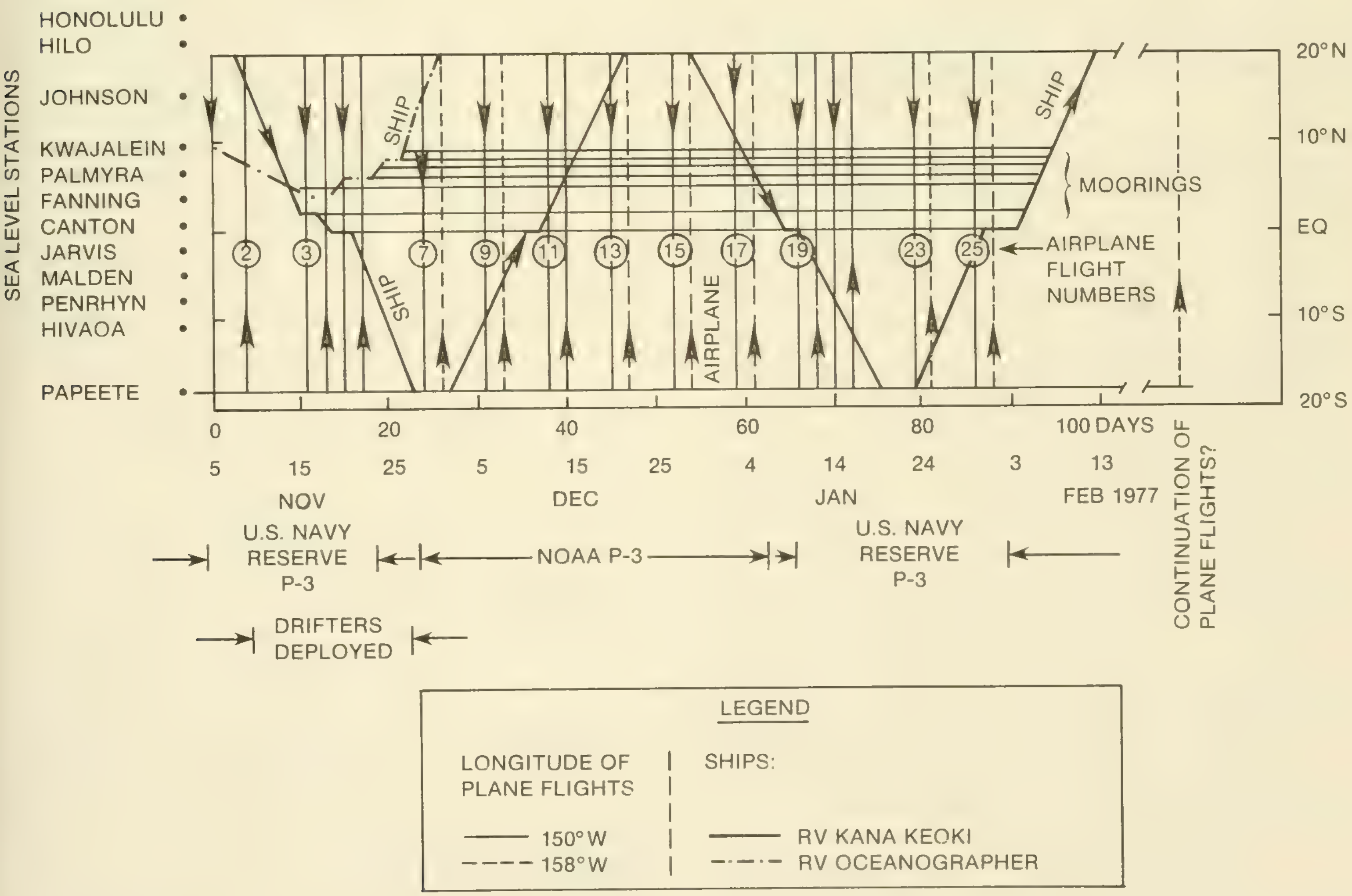

Figure 23.—Time vs. latitude diagram for the NORPAX equatorial test shuttle.

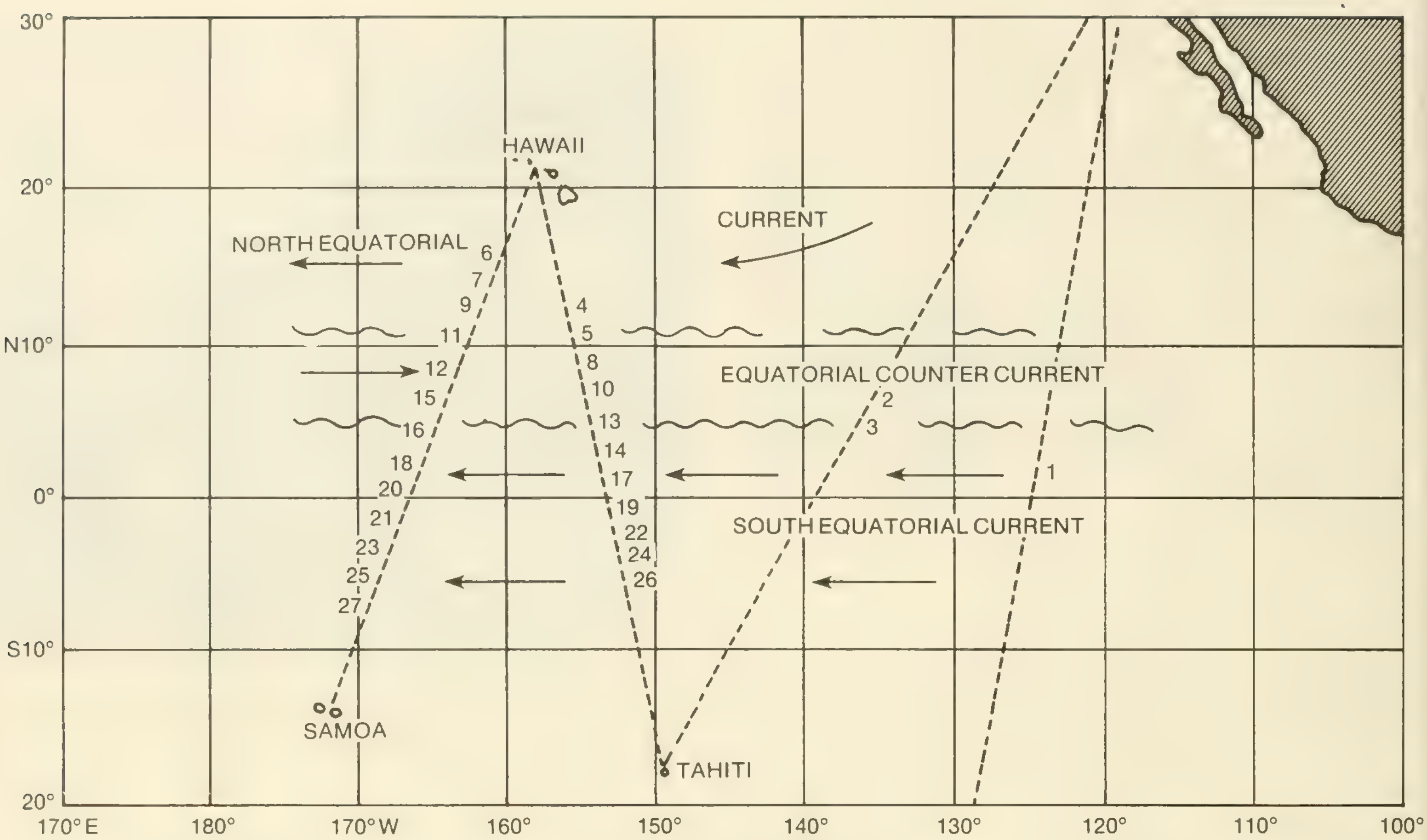

Figure 24.—Location of transequatorial XBT sections 1–27 taken from 1972 to 1975. Major currents are also indicated.

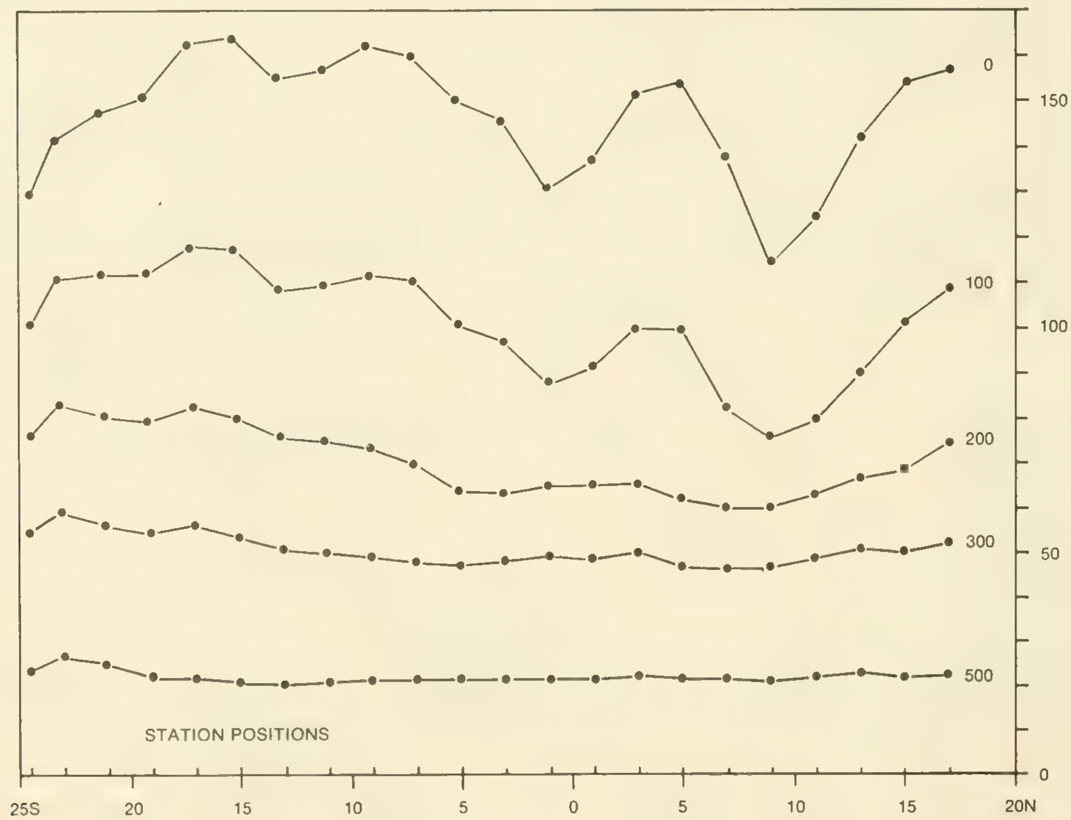

Figure 25.—Profiles of dynamic topography relative to 700 dB along 155°W in September 1969.

Investigator: W. White (SIO)
Grant No.: OCE76–80040
Project: NORPAX/Japanese ships of opportunity
Data: 13,647 MBTs taken aboard 295 cruises of 44 different Japanese ships from January 1968 to December 1975. Data were received on NODC-compatible magnetic tape.

NODC Accession No.: 77–0894
Investigator: W. White (SIO)
Grant No.: NSF/OCE76–80040
Project: NORPAX/TRANSPAC ships of opportunity
Data: 1,178 XBTs from:

SS Dant
Cruise—July 1975, 26–XBTs, Ref. No.: 52320

SS President Harrison
Cruise—July 1975, 9–XBTs, ref. no.: 52321
Cruise—June–July 1975, 16–XBT's, ref. no.: 52322
Cruise—May–June 1975, 15–XBTs, ref. no.: 52323
Cruise—May 1975, 25–XBTs, ref. no.: 52324
Cruise—April 1975, 11–XBTs, ref. no.: 52325

SS President McKinley
Cruise—May 1975, 65–XBTs, ref. no.: 52305
Cruise—June 1975, 80–XBTs, ref. no.: 52306
Cruise—May–June 1975, 73–XBTs, ref. no.: 52307
Cruise—January 1975, 98–XBTs, ref. no.: 52308

SS President Monroe
Cruise—July 1975, 6–XBTs, ref. no.: 52309
Cruise—July 1975, 5–XBTs, ref. no.: 52310
Cruise—April 1975, 13–XBTs, ref. no.: 52311
Cruise—March 1975, 23–XBTs, ref. no.: 52312
Cruise—February 1975, 26–XBTs, ref. no.: 52313

SS President Taft
Cruise—July 1975, 61–XBTs, ref. no.: 52314
Cruise—June 1975, 61–XBTs, ref. no.: 52315
Cruise—June 1975, 22–XBTs, ref. no.: 52316
Cruise—May 1975, 21–XBTs, ref. no.: 52317
Cruise—January–February 1975, 108–XBTs, ref. no.: 52318
Cruise—July 1975, 94–XBTs, ref. no.: 52319

SS President van Buren
Cruise—July 1975, 72–XBTs ref. no.: 52302
Cruise—January 1975, 85–XBTs, ref. no.: 52303
Cruise—December 1974–January 1975 75–XBTs, ref. no.: 52304
Data were received on strip charts.

NODC Accession No.: 77–0524
Organization: University of Hawaii
Investigator: K. Wyrtki (UHI)
Grant No.: OCE74–24583
Project: El Niño Watch
Data: 189 CTDs and serial oceanographic stations—oxygen, phosphates, nitrates, nitrites, silicates, chlorophyll, productivity, and pressures—taken aboard RV Moana Wave Cruise-El Niño Legs 1, 2, 3, and 4 in the eastern tropical Pacific.

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International Southern Ocean Studies (ISOS)

Global atmospheric and oceanic circulation is of particular interest in the southern ocean, because of the strong and variable air-sea exchanges that drive the Antarctic Circumpolar Current System and result in the formation of Antarctic bottom water and intermediate water. Understanding this oceanic-atmospheric circulation is one of the building blocks in a comprehensive theory of global climate dynamics.

The data base available to establish the structure of the mean fields of temperature and salinity in the Southern Ocean is large, but distributed widely in space (from 5 to 200 km) and time. In some locations, observations have been made yearly since 1928, while other locations have only one observation. The data base on variability and response of these fields and of the velocity field is small. In addition, theoretical studies on the dynamics of the interaction of atmospheric and oceanic circulation are few. At present, limited knowledge prohibits construction of even a simple model to describe long-term, large-scale variability in the Southern Ocean, let alone models of the interaction of this region with large-scale global circulation.

The program, International Southern Ocean Studies (ISOS), attempts to improve our understanding of circulation in this region. ISOS draws on current technology and is carried out within the period of the Global Atmospheric Research Program (GARP) and the First GARP Global Experiment (FGGE). Table 7 lists ISOS projects and principal investigators.

The objectives of ISOS are:

1. Identify the statistical properties and space-time scales of variability in selected regions of the Antarctic Circumpolar Current System.

2. Develop and subject to critical test theories of dynamical balance, mixing, and exchange with other oceans.

3. Develop a basis for understanding the role of the large-scale circulation and air-sea interaction in the Southern Ocean in global climate dynamics.

These objectives are being met through monitoring and dynamics experiments in several regions of the Antarctic Circumpolar Current System; analysis of existing data sets; and numerical, analytical, and laboratory modeling.

First Dynamic Response and Kinematics Experiment (F DRAKE)

The first such experiment, entitled F DRAKE, combined a monitoring effort and local experiments. It began in the austral summer of 1974 to 1975 and terminated in December 1977. Earlier issues of *IDOE Progress Reports* describe F DRAKE objectives and experiments.

The ideas obtained, or sharpened, as a result of the F DRAKE studies have changed basic concepts of the structure and variability of the Antarctic Circumpolar Current system. Bands of water masses and velocities in the basic circumpolar current have been established, and "rings" have been observed in the polar frontal zone. The feasibility of long-term, current/temperature meter and pressure gage measurements in the Drake Passage has been demonstrated.

F DRAKE data sets (now up to 3 years long) have shown significant correlations between the currents across the passage and between currents and surface wind. The data set has permitted the most accurate estimate to date of the water transport and its variability in the Drake Passage. In addition, calculations show a poleward heat flux across the passage of a magnitude consistent with global estimates, and show the importance of baroclinic instability in this region. Fluxes calculated using atmospheric parameterization schemes for baroclinic instability-induced eddy transport agree with observed fluxes. All the above data are crucial to the understanding of the role of the Southern Ocean in global climate dynamics.

Regional studies in the Bransfield Strait established renewal times for the waters of this basin and its influence on surrounding waters. A statistical study of all available data from the circumpolar current system set upper limits to the scale of mesoscale turbulence in most parts of the Southern Ocean and its horizontal distribution of intensity.

Five moorings were left in the Drake Passage for 1978 to continue the time series, which are now 3 years long. Two bottom-mounted pressure gages were moored at 500 m on the northern side of the passage; two pressure gages were moored at 500 m on the southern side of the passage. A single current-meter mooring with current meters at 416, 927, and 1,947 m is in the center of the Drake Passage at 59.1°S, 63.76°W. A major experiment, S DRAKE, which may use as many as 30 moorings, is planned for 1979 in the Drake Passage.

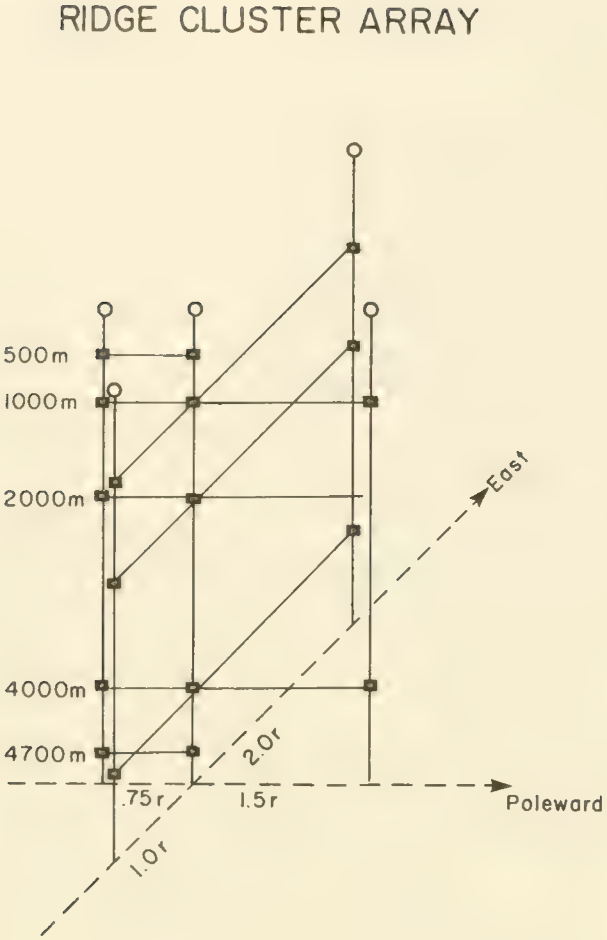
Table 7.—U.S. institutions, investigators, and projects in ISOS

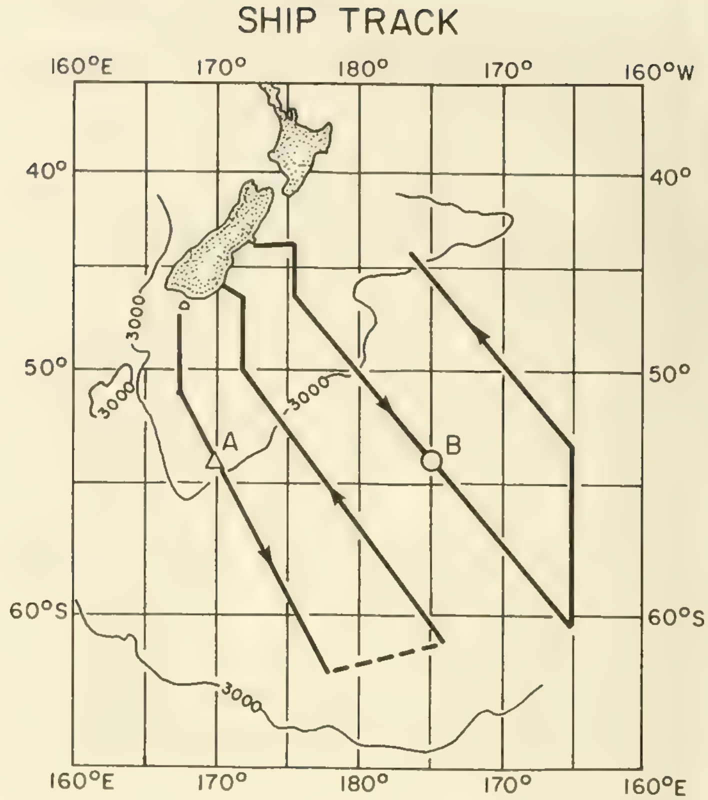
Institutions	Investigators	Projects
Columbia University	D. Giorgi	Circulation of the Southwest Atlantic Ocean
	A. Gordon	Southern Ocean Atlas
NOAA/ERL Pacific Marine Environmental Laboratory	S. Hayes	Macquarie Ridge Hydrographic Study
Nova University	M. Spillane	Quasi-Geostrophic Zonal Jets
Oregon State University	J. Allen	Theoretical Studies of Time-Dependent Flow in the Vicinity of Drake Passage
	R. DeSzoeke	Baroclinic Eddy Dynamics
	L. Gordon	Chemical Observations and Interrelationships in the Southern Ocean
	V. Neal	International Coordination
	R. Pillsbury and C. Fandry	Study of the Long-Term Variability of the Antarctic Circumpolar Current in the Drake Passage
Texas A&M University	W. Emery	A Study of the Thermal Structure South of Australia
	W. D. Nowlin and J. Morrison	Central Administration, Coordination, and Planning
	W. D. Nowlin	Chemical and Physical Oceanography of the Antarctic Circumpolar Current and Frontal Zones: I. Observations in the Drake Passage and Scotia Sea
University of Washington	D. J. Baker and R. Wearn	Transport Measurements of the Antarctic Circumpolar Current and Analysis of Existing Tidal and Meteorological Data
Woods Hole Oceanographic Institution	T. Joyce	Dynamical Observations at the Antarctic Polar Front
	M. McCartney	Southern Ocean Water Mass Renewal and Circulation Southeast of New Zealand
	H. Bryden	A Study of the Dynamics of Low-Frequency Motions of the Antarctic Circumpolar Current South of New Zealand
	W. Jenkins	A Study of Southern Ocean Water Mass Renewal and Circulation Southeast of New Zealand Using Helium Isotope and Tritium

Ridge Interaction and Downstream Gradient Experiment (RIDGE)

In 1978, most of the ISOS experimental work will take place southeast of New Zealand to study the interaction of the Antarctic Circumpolar Current with the Macquarie Ridge. In March, a cluster array of current meters on five moorings (see fig. 26) will be moored at about 54°S, 175°W by the RV Tangaroa, which is operated by the New Zealand Oceanographic Institute. The Tangaroa will also set a near-surface mooring instrumented with thermistor chains east of Campbell Island about 54°S, 170°E. The RV Knorr will pick up these moorings in November after doing extensive hydrographic work in the region in late September and October.

The objective of the cluster array of current meters is to study the dynamics of low-frequency motions and their effects on the Antarctic Circumpolar Current. The region near Macquarie Ridge was chosen for these measurements, because observational, theoretical, laboratory, and numerical model results suggest that the interaction of the Antarctic Circumpolar Current with Macquarie Ridge generates low-frequency fluctuations, and that these fluctuations may be important in the overall dynamics of the circumpolar current. This cluster array is an exploratory array. Time series of currents and temperatures have not been previously measured in the region; the primary results will be estimates of energy levels and spatial and temporal scales for the low-frequency motions. Poleward heat fluxes and perhaps momentum fluxes should be significant, and the mechanism which causes these fluxes will be explored. If these fluxes can be related to large-scale gradients of temperature and vorticity, the effects of the fluctuations can be parameterized in large-scale models of ocean circulation.





Cruise tracks for the two *KNORR* cruises. The southern end of the sections will be determined by ice conditions. Thermistor chains will be moored at A, and the current meter cluster array will be moored at B.

Figure 26.—ISOS experiment ridge cluster array and ships tracks.

The thermistor chain mooring monitors the development of winter deep-mixed layers in the upper waters of the subantarctic zone. Temperature will be recorded over the upper 600 m from early fall through midspring 1978. The analysis of the thermistor chain data (and associated hydrographic work done from the TANGEROA and KNORR) will focus on the seasonal convective renewal of subantarctic-mode water. The 8°C subantarctic-mode water is found upstream, south of the Tasman Sea, and apears to be converted to 7°C subantarctic-mode water by air-sea heat exchange over the Campbell Plateau. Analysis and interpretation of the data will be supplemented by the meteorological data routinely collected at Campbell Island, 100 nmi northwest of the mooring.

The hydrographic program from the KNORR will be used for study of several features. The formation of the deep western boundary current in the southwest Pacific Basin will be studied: how does the transition from the observed zonal flow along the midocean ridge at 170°E, 62°S to the observed meridional flow at 43°S, 168°W occur? The intensity and variability of winter-overturned water in the polar frontal zone and in the antarctic zone will be studied. Data will be gathered to study the smaller scale structure of the polar frontal zone. Interpretation of the various water mass structures (subantarctic-mode water, antarctic-intermediate water, and deep water) will be aided by a tritium and helium isotope sampling program.

An intensive study of the polar frontal zone will be made at 58°S, 165°E on the last leg of the KNORR cruise in December 1978. The Antarctic Circumpolar Current seems to have a permanent meander over the Macquarie Ridge near this location, and barotropic models show that the region could be an active generator for eddies. Because of large lateral gradients at this location, interleaving could also be greatly enhanced. A closely spaced CTD section will be made across the polar front, and XBTs will be used to map the local mesoscale structure of the polar frontal zone and to study the spatial persistence of interleaving. Two vertical current meters will be placed in the polar frontal zone and tracked for a 2- to 3-day period with repeated CTDs over the floats. This data set will be suitable for analysis of fine-structure statistics. By using data from the earlier KNORR cruises, a comparison between broad and narrow polar frontal zones will be possible. By comparing results to those obtained in the Drake Passage in 1976, the universality of the interleaving properties of the circumpolar front can also be studied.

Observations of the Polar Frontal Zone

To study further the variability of the polar frontal zone, XBT sections were taken from vessels crossing the Antarctic Circumpolar Current south of New Zealand, Australia, and South America during the austral summers of 1976–77 and 1977–78. Figure 27 shows the tracks of vessels making these observations in the region of the Drake Passage. Figure 28 shows results from one of these sections. Frontal boundaries between different water masses are evident in XBT temperature sections. At the southern end of the passage close to the South Shetland Islands, a subsurface isothermal layer of cold water, called Antarctic Continental Water, can be seen. This layer is bordered on the north by a strong subsurface (>150m) temperature gradient, the Continental Water Boundary (CWB). North of the CWB in the upper 200 m is the cold Antarctic Surface Water (ASW). Formed during the winter, this water mass is characterized in summer by a subsurface temperature minimum. At the northern terminus of the temperature minimum, a strong temperature gradient is found—this temperature gradient is called the polar front (an operational definition of the polar front adopted by ISOS workers is the northern edge of the 2°C isotherm). North of the polar front is the Antarctic polar frontal zone. The northern boundary of the Antarctic polar frontal zone is the subantarctic front. The thermal expression of the subantarctic front is a subsurface temperature gradient between 2° and 5°C.

The series of sections collected during 12 crossings of the Drake Passage in the austral summer of 1976–77 indicated the development of cold features within the Antarctic polar frontal zone. These cold features are most likely expressions of eddies or meanders formed at the polar front. They appear to widen the Antarctic polar frontal zone by intensifying the subantarctic front and moving it to the north. The majority of the temperature sections contain such cold features, whose signature could be identified as an inflection in average profiles of 450 m heat content and sea-surface temperature.

Observations made by American and Soviet scientists on the RV PROFESSOR ZUBOV in the polar frontal zone south of Australia along 132°E between January 24 and March 1, 1977, provided a more detailed view of the structure of the polar frontal zone. A strong cyclonic eddy, containing ASW, from south of the polar front, was found to the south of and combined with a meander of the subantarctic front. Current meters

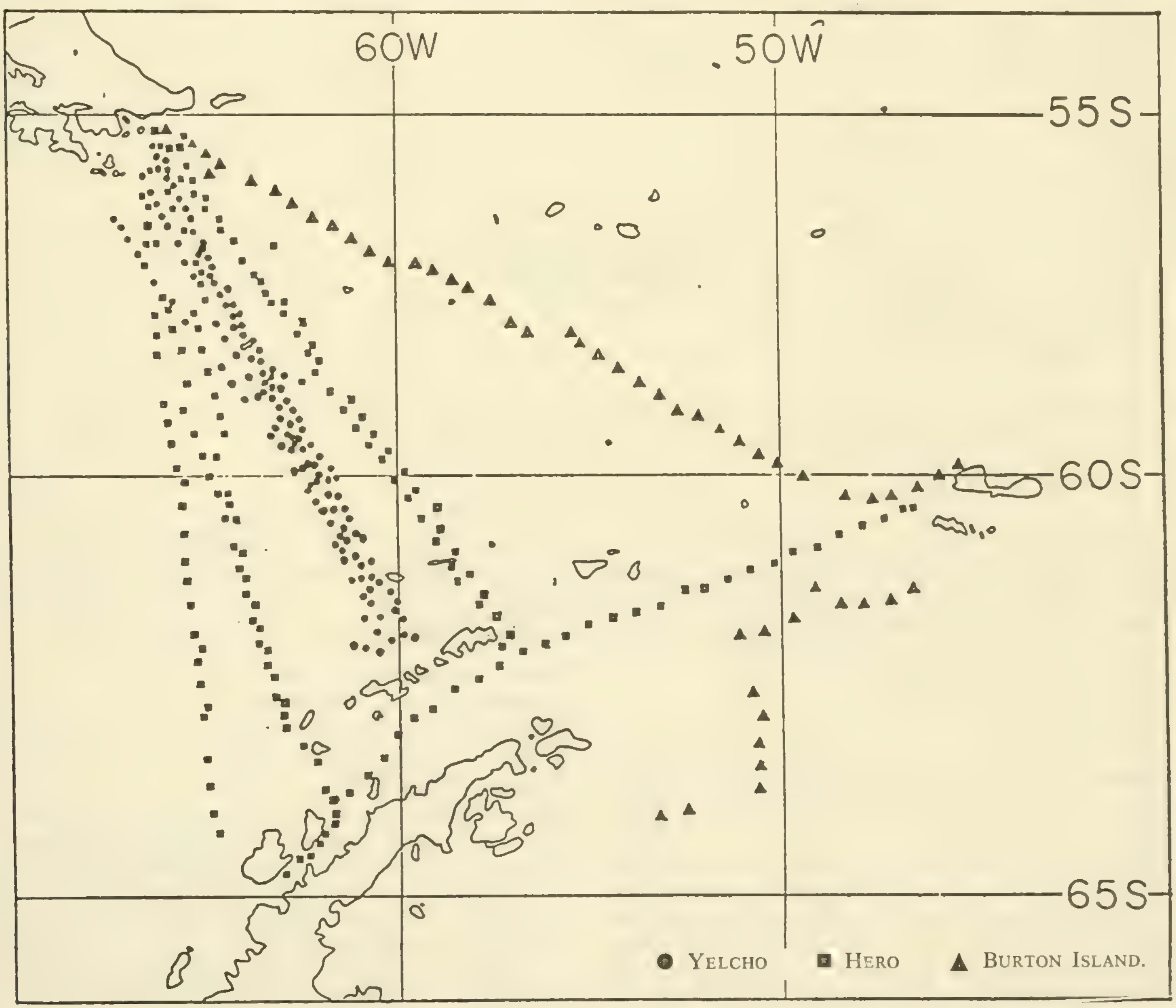


Figure 27.—Position of XBT observations in the Drake Passage 1976–77.

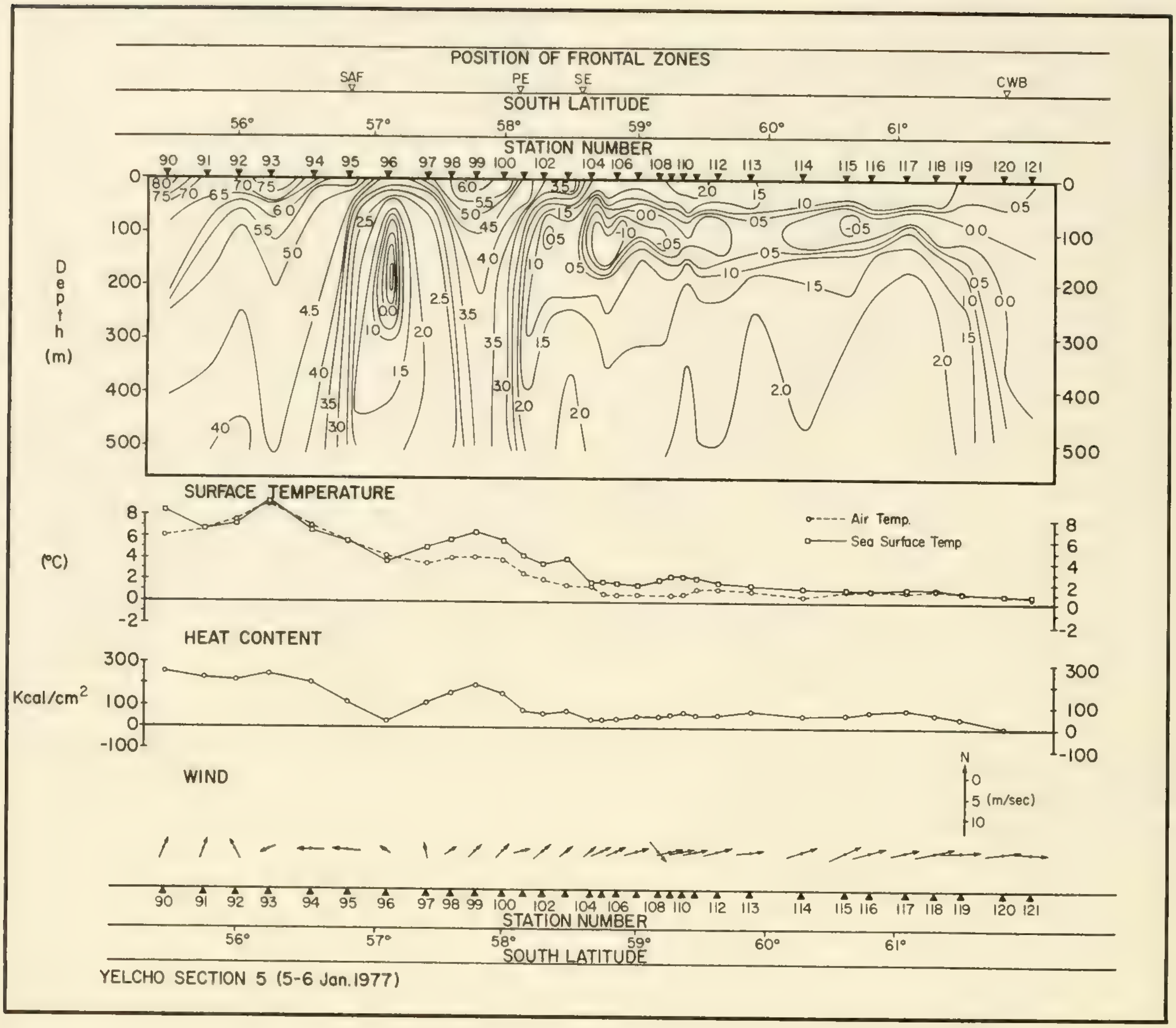


Figure 28.—Oceanographic and meteorological observations from a Ship-of-Opportunity (R/V YELCHO) crossing of Drake Passage, 5–6 January 1977.

moored in and north of the eddy indicated deep flow to the west, and suggested anticyclonic circulation below 2,000 m. Three XBT surveys along with the current-meter records indicated that the eddy moved north-northeastward at an average speed of 3 cm/s. Figure 29 illustrates a schematic, three-dimensional picture of the eddy.

Other ISOS Studies

A Southern Ocean Atlas of Physical and Chemical Oceanographic data by Arnold Gordon is nearing completion. It should be published in late 1979.

The extent of international collaboration in ISOS should be emphasized. During the next year, Chile and New Zealand will contribute ship time and scientists to ISOS studies. Argentina, Australia, and the Soviet Union will also carry out studies of the circumpolar current, the former effort complementing RIDGE studies. Australia, Chile, and the Soviet Union are collaborating in obtaining XBT sections for joint scientific study; Australia and South Africa are observing the circumpolar current using drogued, satellite-interrogated, drifting buoys.

ISOS Data

ISOS data are available from NODC as follows:

NODC Accession No.: 78–0194
Organization: Texas A&M University
Investigator: W. J. Emery (TAMU)
Grant No.: OCE76–81371
Project: F DRAKE 76
Data: All XBTs are on NODC-compatible magnetic tape, were taken in various parts of the southern ocean, January to March 1976, and are listed by vessel, originator's cruise no., NODC Ref. No., and number of XBT's: RV PROFESSOR ZUBOV, 9018ZB01, 052476, 188; RV THALLA DAN, 0903TD01, 052477, 173; RV NELLA DAN, 0903ND01, 052478, 135; RV YELCHO, 2009YE04, 052479, 143; RV HERO, 31296J01, 052480, 60; USCGS NORTHWIND, 3106NW01, 052481, 198; USCGS BURTON ISLAND,

3106BI01, 052482, 65; USCGS Burton Island, 3106-BI02, 052483, 106; USCGS Burton Island, 3106BI03, 052484, 47.

NODC Accession No.: 78–0191
Organization: Texas A&M University
Investigator: W. Nowlin (TAMU)
Grant No.: ID075–04547
Project: F DRAKE 76
Data: Cruise Thomas G. Thompson F DRAKE 76 leg 1, 2/4/76 to 2/22/76, 42 Ocean Stations in Drake Passage; leg 2, 2/23/76 to 3/9/76, 42 Ocean Stations in Drake Passage. Data include temperature, salinity, depth, oxygen, phosphates, phosphites, and silicates; all were submitted on punched cards and printout.

NODC Accession No.: 77–00720
Organization: U.S. Coast Guard
Investigator: NSF Office of Polar Projects
Grant No.: No IDOE Grant
Project: ISOS/Ross Ice Shelf Project (RISP)
Data: 104 XBTs taken aboard USCGS Burton Island, Leg 1, 1/19 to 1/31/76, Leg 2, 2/5 to 2/10/76. Data submitted on log sheets and strip charts.

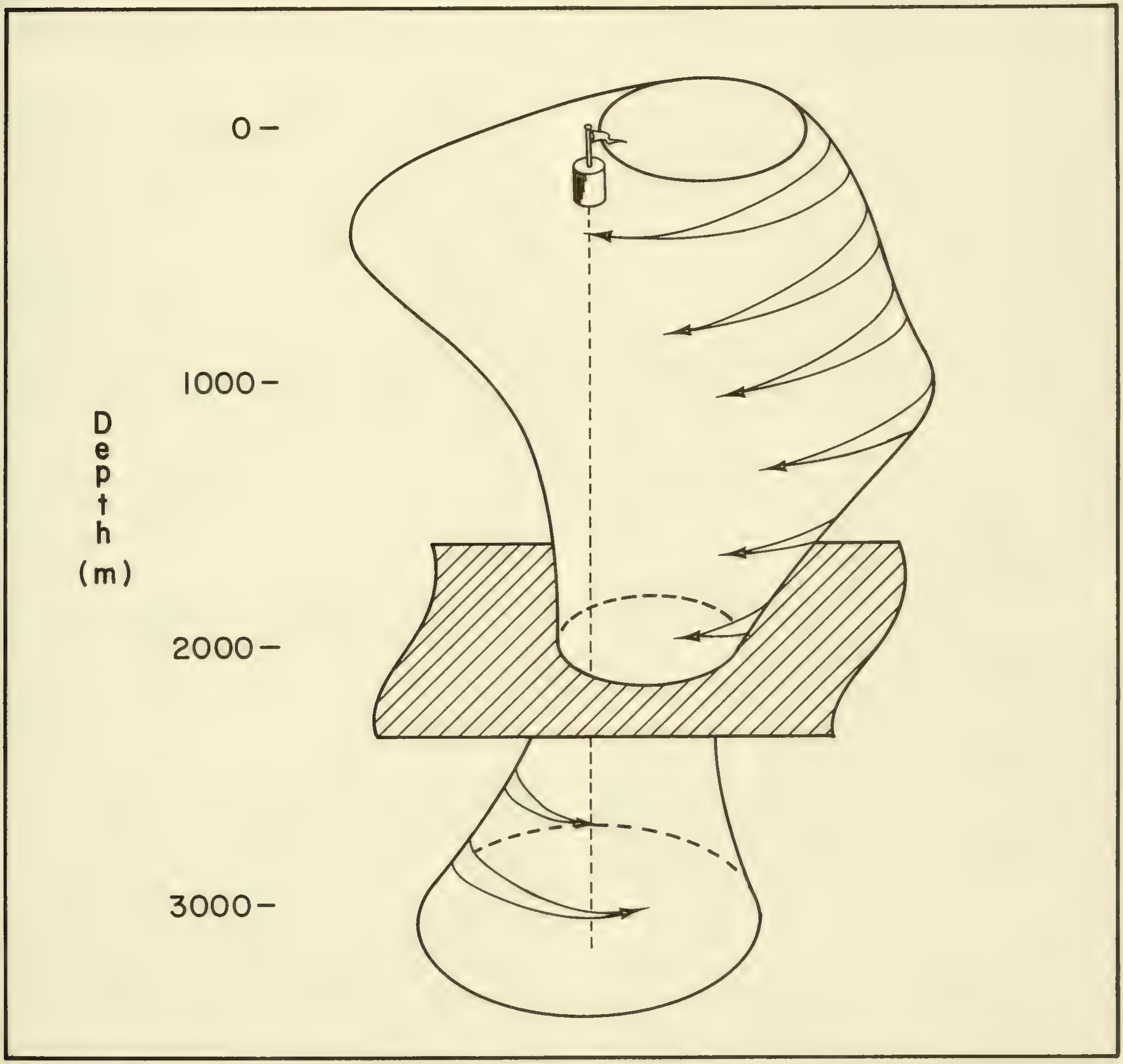


Figure 29.—Schematic three-dimensional picture of an eddy observed by Soviet and American scientists south of Australia in 1977. The buoy indicates the vertical axis only.

NODC Accession No.: 77–0538
Organization: Texas A&M University
Investigator: W. Nowlin (TAMU)
Grant No.: OCE74–14941
Project: F DRAKE 75
Data: 63 serial oceanographic stations taken aboard RV MELVILLE, February 18 to March 4, 1975, in the Drake Passage.

NODC Accession No.: 77–0460
Organization: Texas A&M University
Investigator: S. Patterson (TAMU)
Grant No.: OCE74–04941 A02
Project: F DRAKE 76
Data: 328 XBTs taken aboard AGS YELCHO, 3/24 to 4/5/76. Data submitted on NODC-compatible magnetic tape.

NODC Accession No.: 77–0460
Organization: Texas A&M University
Investigator: W. Nowlin (TAMU)
Grant No.: OCE74–14941 A02
Project: F DRAKE 76
Data: 68 XBTs taken aboard RV THOMAS G. THOMPSON, Cruise TT–02, 2/26 to 3/8/76. Data submitted on NODC-compatible magnetic tape.

NODC Accession No.: 77–0460
Organization: Texas A&M University
Investigator: W. Nowlin (TAMU)
Grant No.: OCE74–14941 A02
Project: F DRAKE 76
Data: 63 XBTs taken aboard RV THOMAS G. THOMPSON, Cruise TT–01, 2/8 to 2/21/76. Data submitted on NODC-compatible magnetic tape.

NODC Accession No.: 77–0460
Organization: Texas A&M University
Investigator: S. Patterson (TAMU)
Grant No.: OCE74–04941 A02
Project: F DRAKE 76
Data: 240 XBTs taken aboard AGS YELCHO, Cruise YE–01, 2/28 to 3/10/76. Data submitted on NODC-compatible magnetic tape.

NODC Accession No.: 77–0364
Organization: Oregon State University
Investigator: R. D. Pillsbury (OSU)
Grant Nos.: OCE74–12558, IDO74–14941
Project: F DRAKE 75
Data: 25 files subsurface current measurements, and temperatures; 84,850 data sets and 1,807 sets of tide data, taken on RV MELVILLE from February 22 to May 14, 1975, in Drake Passage, submitted on NODC-compatible magnetic tape.

NODC Accession No. 77–0357
Organization: University of Washington
Investigator: V. Neal (U Wash.)
Grant No.: GX–42577
Project: ISOS Under Ice Hydrographic Data
Data: Temperatures and salinities obtained through the ice in McMurdo Sound from September 12 to October 6, 1974, submitted as a data listing.

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Climate: Long-Range Investigation, Mapping, and Prediction (CLIMAP) Study

CLIMAP research is designed to describe and explain the major changes in global climate that have occurred in the past million years. These changes involve transitions between two partly stable states of global climate—ice ages and temperate (interglacial) periods. The fundamental objective is to improve our understanding of the causes of long-term climatic change. Previous CLIMAP work has firmly established a concept suggested by earlier workers that variation in the Earth-Sun orbital geometry is the pacemaker of long-term climatic change. Much of current CLIMAP work is directed toward studies of the interaction of the various parts of the global climate system. Ocean sediment cores are multichannel recorders of changes in the ocean circulation, variation in the size of ice sheets, and changes in terrestrial climate. Knowledge of how these parts of the global system have interacted in the past provides insight into some of the causal relationships that will determine the climate of the future. These long-range trends are the fundamental, large-amplitude rhythms that underlie the higher frequency and smaller scale variations of recent centuries.

NSF's Climate Dynamics Research Section and the IDOE Section jointly fund CLIMAP studies. CLIMAP scientists are listed in table 8, and CLIMAP task groups in table 9.

Investigation of the Last Interglacial Period

The year 1977 has been one of transition for CLIMAP. With the data-gathering and synthesizing effort for the 18,000 before present (B.P.) ice-age maximum experiment ended, CLIMAP has begun a major new project to reconstruct the climate of the last interglacial period. Its purpose is to make a global study of the sequence of climatic events that occur when climate changes from a time of maximum global ice volume through an ice-volume minimum (the interglacial) and back to conditions of re-expanded global ice. Because we live today in an interglacial climate, this experiment should increase our understanding of the changes toward glacial climates expected in the future.

The project has two major parts. First, CLIMAP scientists will construct a map of the Earth's surface at the time of minimum global ice extent, 125,000 years ago, for comparison with the Earth's surface today. The second part focuses on leads and lags between various parts of the climate system as the Earth goes into and comes out of an interglacial period. Two preliminary examples of these lead/lag relationships shown in figure 30 indicate that in certain parts of the world (notably the subantarctic) sea-surface temperatures warmed before land ice began to melt and cooled before land ice again began to grow. In other areas (the subpolar North Atlantic), the opposite is true. Thus changes in the ocean temperatures of the high-latitude oceans of the Southern Hemisphere lead the ice-volume variations and significantly lead the changes in high-latitude Northern Hemisphere oceans.

Spectral Investigations of Long Periods

One major advance in CLIMAP research this year was the publication of additional documentation of the influence of the Earth's orbital geometry on climate. Adding to earlier work from Indian Ocean subantarctic cores, CLIMAP researchers found in both the Atlantic and Pacific Oceans clear evidence of a concentration of spectral power at the three orbital frequencies (100,000 years, 43,000 years, and 22,000 years). (See fig. 31.) In addition, cross-spectral analysis of isotopic and chemical data indicates that changes in global ice volume led variations in carbonate preservation in the equatorial Pacific cores by several thousand years (fig. 32).

Spectral Analysis of Short Periods

The varved sediments of the Santa Barbara Basin offer a unique opportunity to study the changes in oceanographic conditions there during the last 8,000 years. Analysis of the radiolaria found in a varved sediment core from the Santa Barbara Basin yields an 8,000-year continuous record sampled every 25 years.

Past sea-surface temperatures were calculated from the radiolarian fauna (fig. 33). Results indicate that intervals from 800 to 1,800, 3,600 to 3,800, and 5,400 to 8,000 years B.P. were warmer than today. The warm interval from 5,400 to 8,000 B.P. is a time when pollen analysis indicates a more humid environment for southern California, a condition consistent with warmer sea-surface temperatures. The spectra of the sea-surface temperature record for the Santa Barbara Basin shows that the fluctuations are not random, with much of the variance in the record explained by low-frequency components (fig. 34).

The 18,000 B.P. Experiment

The global map of the ice-age world has been completed. The analytical and stratigraphic error of each transfer-function estimate of sea-surface temperature was categorized and documented for all 245 cores used in the ice-age reconstruction. Digitized maps of the final reconstruction were delivered to several general circulation modelers for simulation experiments during the next year.

Changes in the Antarctic Ocean

The Antarctic Task Group has investigated changes in sea ice cover around the Antarctic Continent between the last glacial period and today. The results indicate that ice in the Antarctic Sea was then much more extensive in the winter than today (40 million km^2 vs. 20 million km^2 today). (See fig. 35.)

Table 8.—CLIMAP Scientists

Executive Committee

R. Cline, Columbia University (Administrator)
G. Denton, University of Maine
J. Hays, Columbia University
W. Hutson, Oregon State University
J. Imbrie, Brown University
A. McIntyre, Columbia University
T. Moore, University of Rhode Island
W. Prell, Brown University
W. Ruddiman, Columbia University

Senior Scientific Investigators

Brown University: N. Kipp, R. Matthews, T. Webb
Columbia University: L. Burckel, B. Kolla, G. Kukla, Y. H. Li, B. Mofino, N. Opdyke, S. Streeter, P. Thompson
University of Maine: T. Hughes, T. Kellogg
Oregon State University: L. Hogan
Princeton University: H. Sachs
University of Rhode Island: P. Dauphin, R. Heath

National Corresponding Members

W. Balsam, Southampton College
R. Barry, University of Colorado
M. Bender, University of Rhode Island
M. Briskin, University of Cincinnati
K. Bryan, Geophysical Fluid Dynamics Laboratory, NOAA
H. Fritts, University of Arizona
J. Gardner, U.S. Geological Survey
W. Gates, Oregon State University
D. Hahn, Geophysical Fluid Dynamics Laboratory, NOAA
L. Heusser, Tuxedo, N.Y.
J. Kennett, University of Rhode Island
R. Ku, University of Southern California
J. Kutzbach, University of Wisconsin
S. Manabe, Geophysical Fluid Dynamics Laboratory, NOAA
R. Newell, Massachusetts Institute of Technology
D. Schnitker, University of Maine
H. Schrader, Oregon State University
H. Thierstein, Scripps Institution of Oceanography

International Corresponding Members

B. Andersen, University of Bergen
A. Berger, Catholic University of Louvain
K. Bjorklund, University of Bergen
W. Dansgaard, University of Copenhagen
J. Duplessy, Center for Radioactive Research
H. Lamb, University of East Anglia
J. Lozano, National University of Colombia
B. Luz, Hebrew University of Jerusalem
M. Sarnthein, Geological Paleontological Institute of Kiel
N. Shackleton, University of Cambridge
E. Siebold, Geological Paleontological Institute of Kiel
J. Thiede, University of Oslo
T. van der Hammen, University of Amsterdam
T. Wjimstra, University of Amsterdam

Soviet-American Atlas Project

CLIMAP's data base from over 725 deep-sea cores will be the basis for a biogeographic atlas to be published as part of a joint U.S.-U.S.S.R. monograph series. This work will stand as a collected reference for micropaleontologists, paleoceanographers, and paleoclimatologists for many years to come.

CLIMAP Data

CLIMAP data received during the period of this report are available from NGSDC as follows:

Magnetic tape, data compilation, UPDATE2, 29,028 data records including corrections and new data on biology, chemistry, and time-stratigraphic relationships in ocean cores (HAYS OCE71–04204).

Analytical data from 934 cores (see fig. 36) consist of:

Geochemistry (450 cores)—geochemical data include percentages of opal (average 2 replicates), percentages of quartz (average 2 replicates), and percentages of carbon.

Paleontology (701 cores)—Paleontological data include numerical data for 75 species of coccoliths, 21 species of radiolaria, 51 species of diatoms, and 44 species of foraminifera.

Stratigraphy (452 cores)—data include one or more of the following: percentages of fine carbonate (<63 mμ), percentages of coarse carbonate (>63 mμ), and percentages of total carbonate.

Chronology (42 cores)—data include upper- and lower-interval limits, estimated ages, and upper- and lower-age errors.

In addition, each data record contains the following information:

1. Ship-core number
2. Latitude, longitude, and water depth
3. Core type, length, and sample depth within core.

The CLIMAP data set is available on 7- or 9-track, coded, magnetic tape, at any compatible density, with a logical record length of 80 characters, blocked (5,120 characters or less) or unblocked. Documentation and format of the data are provided in print form and also appear in text form at the beginning of the tape.

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Table 9.—CLIMAP Task Groups

Leaders	Tasks
L. Burckle	Diatoms
G. Denton	Ice Margin
J. Hays	Antarctic
J. Hays	Biostratigraphy
J. Hays	Radiolaria
L. Hogan	Volcanic Dating
T. Hughes	Ice Sheet Reconstruction
W. Hutson	Data Bank
J. Imbrie	18,000 B.P. Numerical Experiment
J. Imbrie and N. Pisias	Spectral Analysis
N. Kipp	Planktonic Foraminifera
N. Kipp and B. Molfino	South Atlantic Ocean
G. Kukla	Albedo
G. Kukla	Land-Sea Correlation
A. McIntyre	Coccoliths
A. McIntyre	Global Mapping
A. McIntyre	North Atlantic Ocean
T. Moore	Pacific Ocean
N. Opdyke	Paleomagnetics
W. Prell	Indian Ocean
W. Ruddiman	120,000 B.P. Experiment
N. Schackleton, R. Mathews, and Y. H. Li	Oxygen Isotope
S. Streeter	Benthonic Foraminifera
J. Thiede, J. Thunnell	Mediterranean Sea

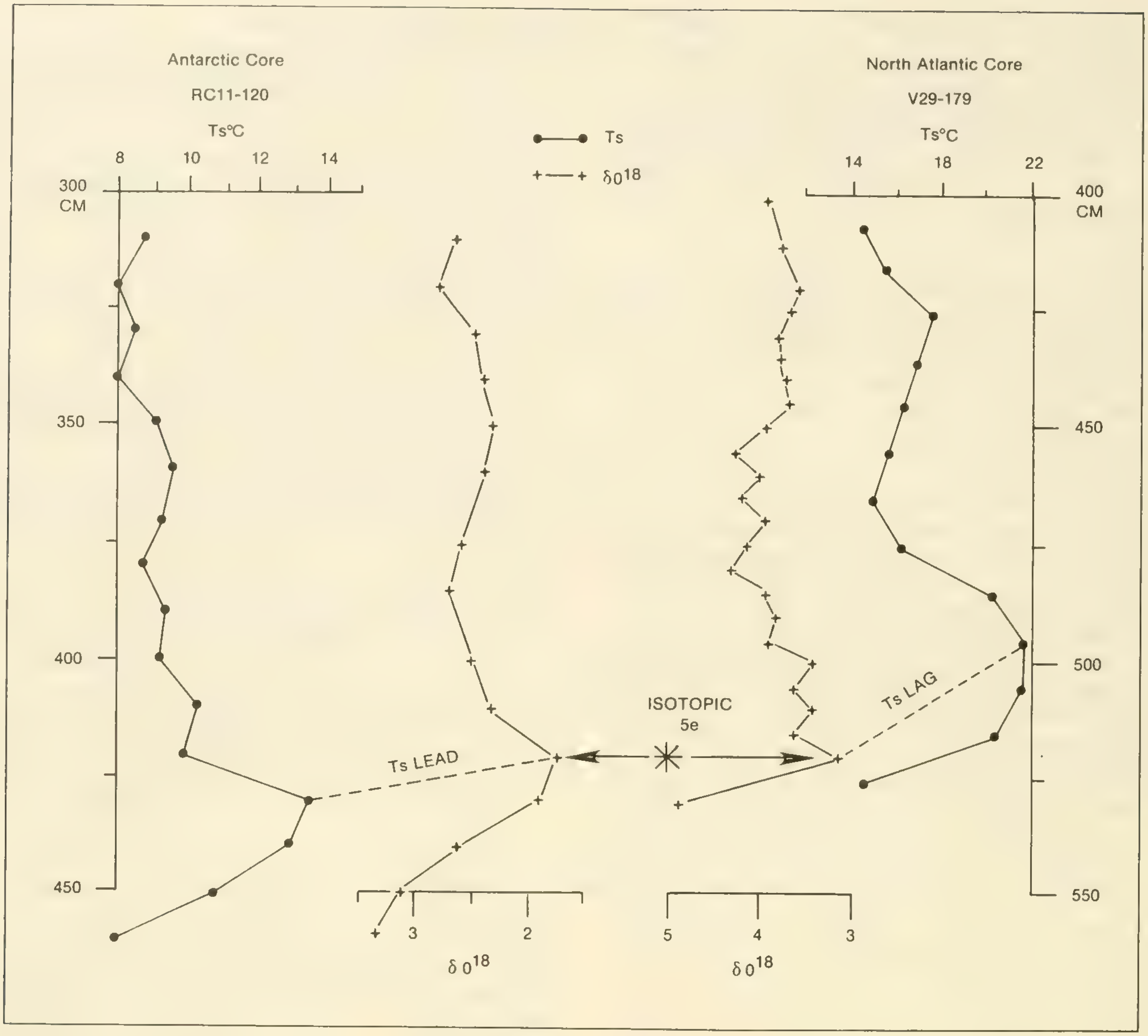

Figure 30.—Changes in sea-surface temperature compared to isotopic curves in high-latitude cores from the Northern and Southern Hemisphere. Isotopic curves largely reflect global ice volume. Warmest Antarctic sea-surface temperatures led, and warmest North Atlantic temperatures lagged the ice-volume minimum of the last interglacial. Ts is surface temperature. 5e is an isotope stage associ - ated with the last interglacial.

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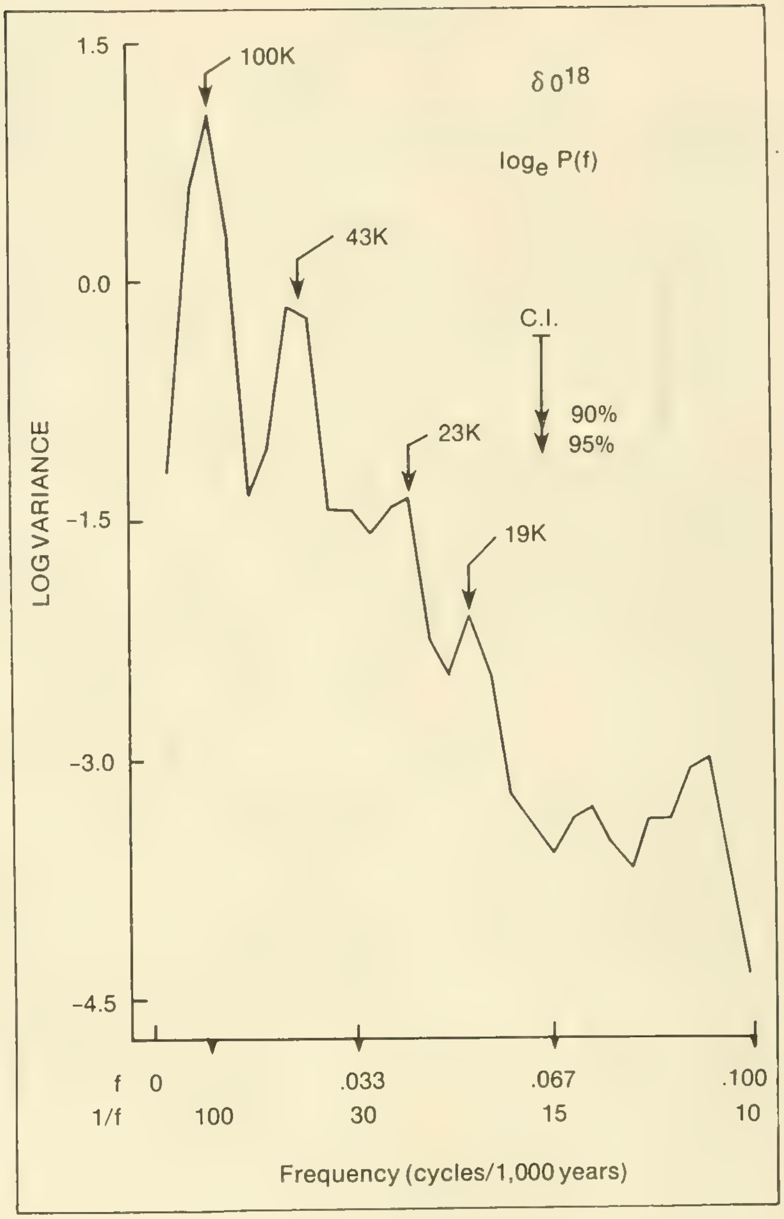
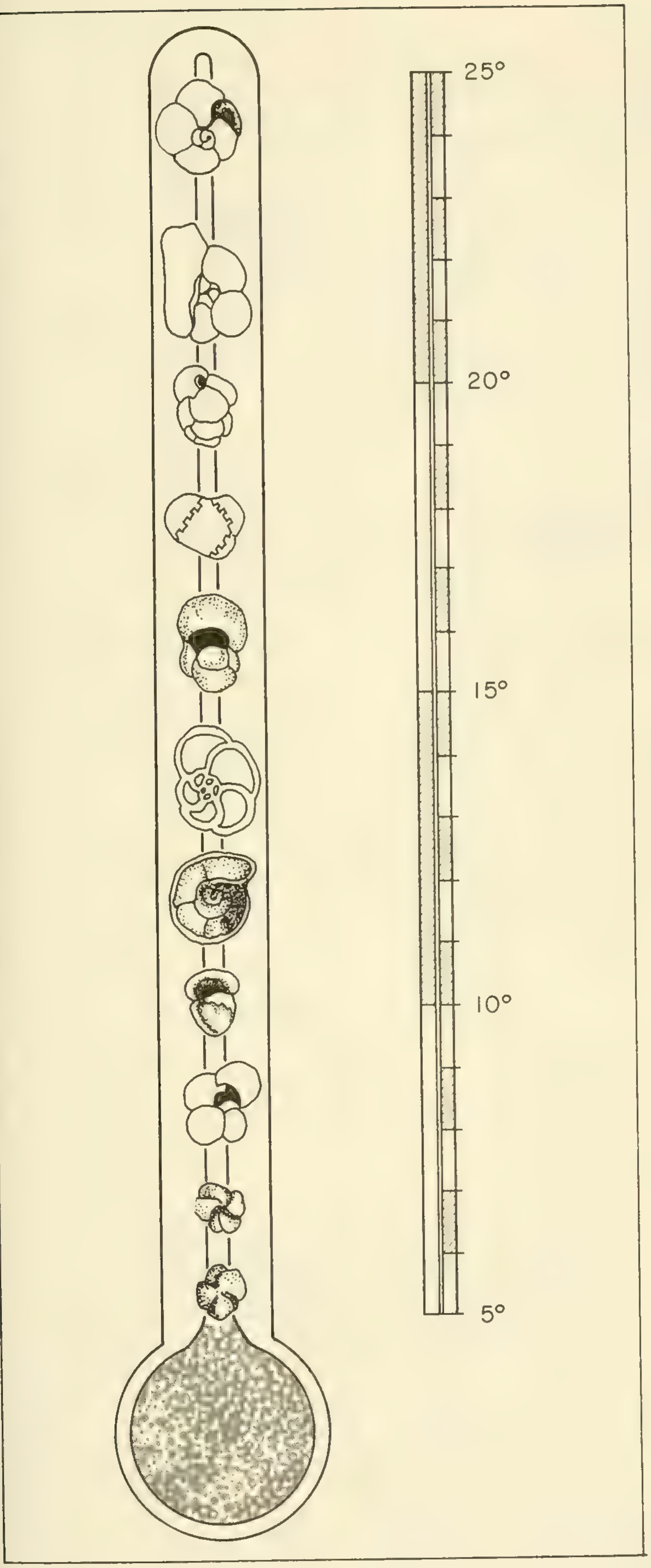


Figure 31.—Spectra of climatic variations in $\delta\ 0^{18}$ record in deep-sea core RC13–229 from the South Atlantic (25°S, 11°E). High-resolution spectra are expressed as the natural log of the variance as a function of frequency (cycles per thousand years). Arrows point to spectral peaks with cycle lengths of 100,000 years, 43,000 years, 23,000 years and 19,000 years, which are similar to periods of orbital parameters. C.I. = confidence interval. P = power or variance. K = 1,000 years.



A paleothermometer that illustrates the principle involved in transforming fossil sediments into estimates of sea-surface temperature. Fossil microorganisms, such as the species of foraminifera shown, live near the ocean surface, then die, sink, and concentrate in bottom sediments. When large numbers of a certain species are found in a sediment layer, this indicates a particular surface temperature, favorable to their growth.

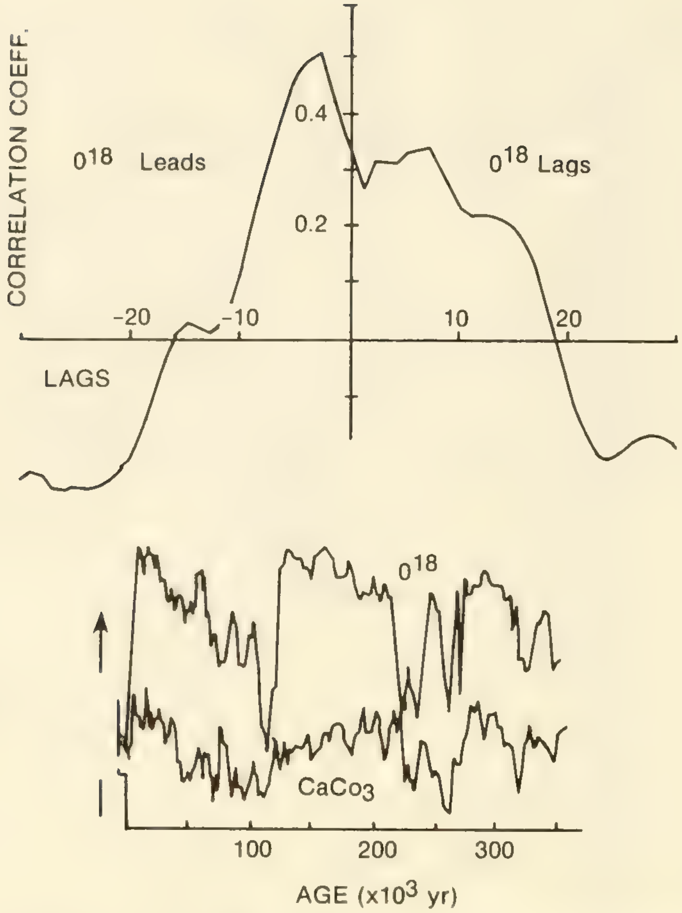


Figure 32.—Cross correlation of oxygen isotopes and carbonate concentrations in core V19–29. At the bottom, the number of sample intervals indicated by the maximum correlation offsets plots of the two records.

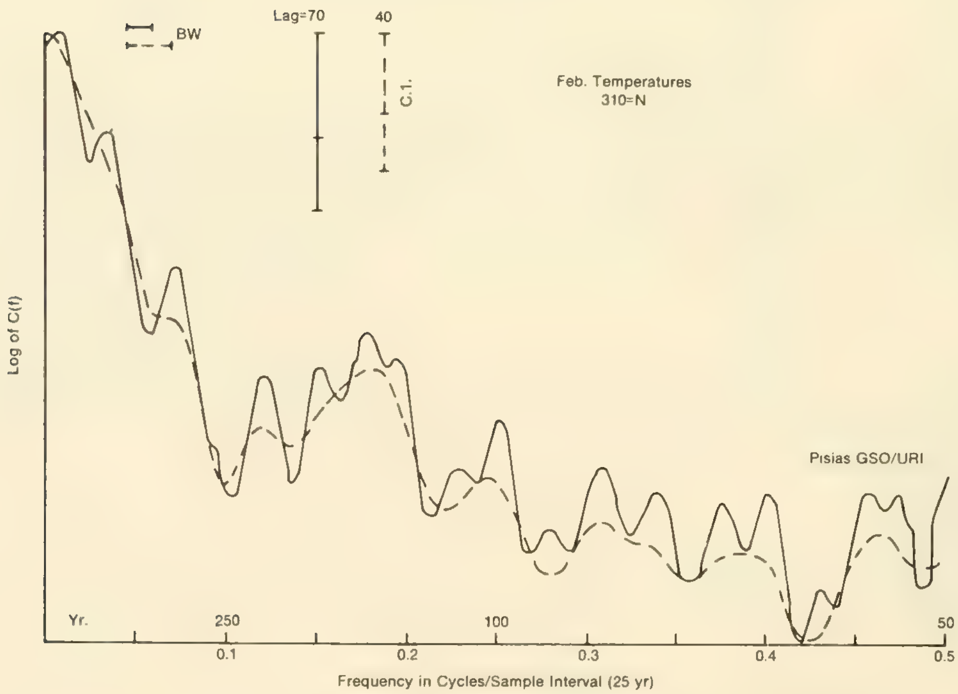


Figure 33.—Spectra for unsmoothed February sea-surface time series. BW = Bandwidth of smoothing window, C.I. = 80 percent confidence for spectral estimates, Lag = number of autocorrelation values used to calculate spectra, N = number of data points in time series. C(F) = temperature variance.

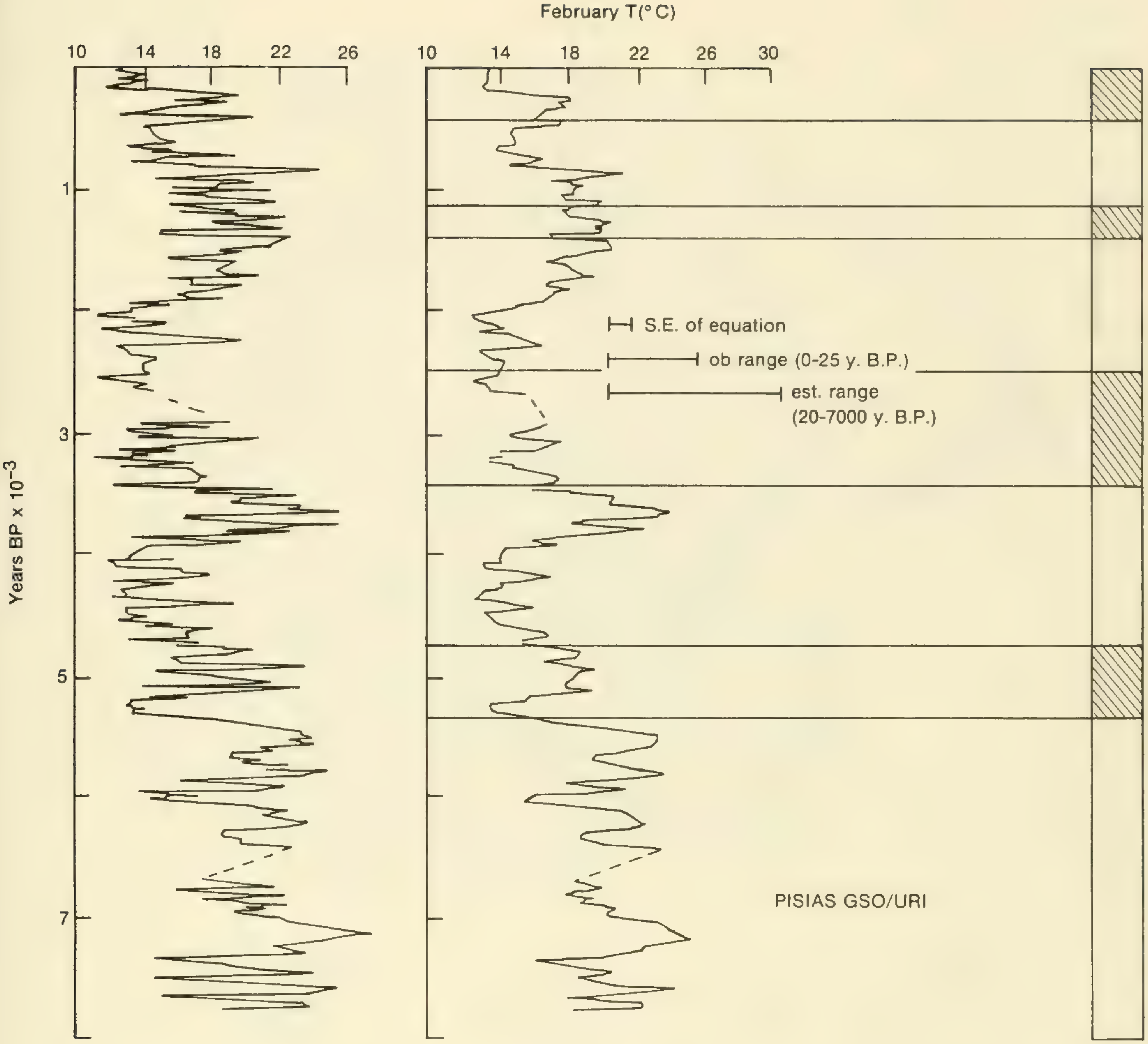


Figure 34.—February sea-surface temperatures for the Santa Barbara Basin. S.E. = standard error of estimates, ob Range = observed temperature range for the southern California borderland from historical hydrographic data, est. range = estimated range for the last 7,000 years. Shaded areas in column to right indicate time of alpline advances during the Holocene (Denton and Karlen 1971). Top of time bar equals 1,850 A.D. Left figure is raw data, right figure is low pass filtered with three-point moving average.

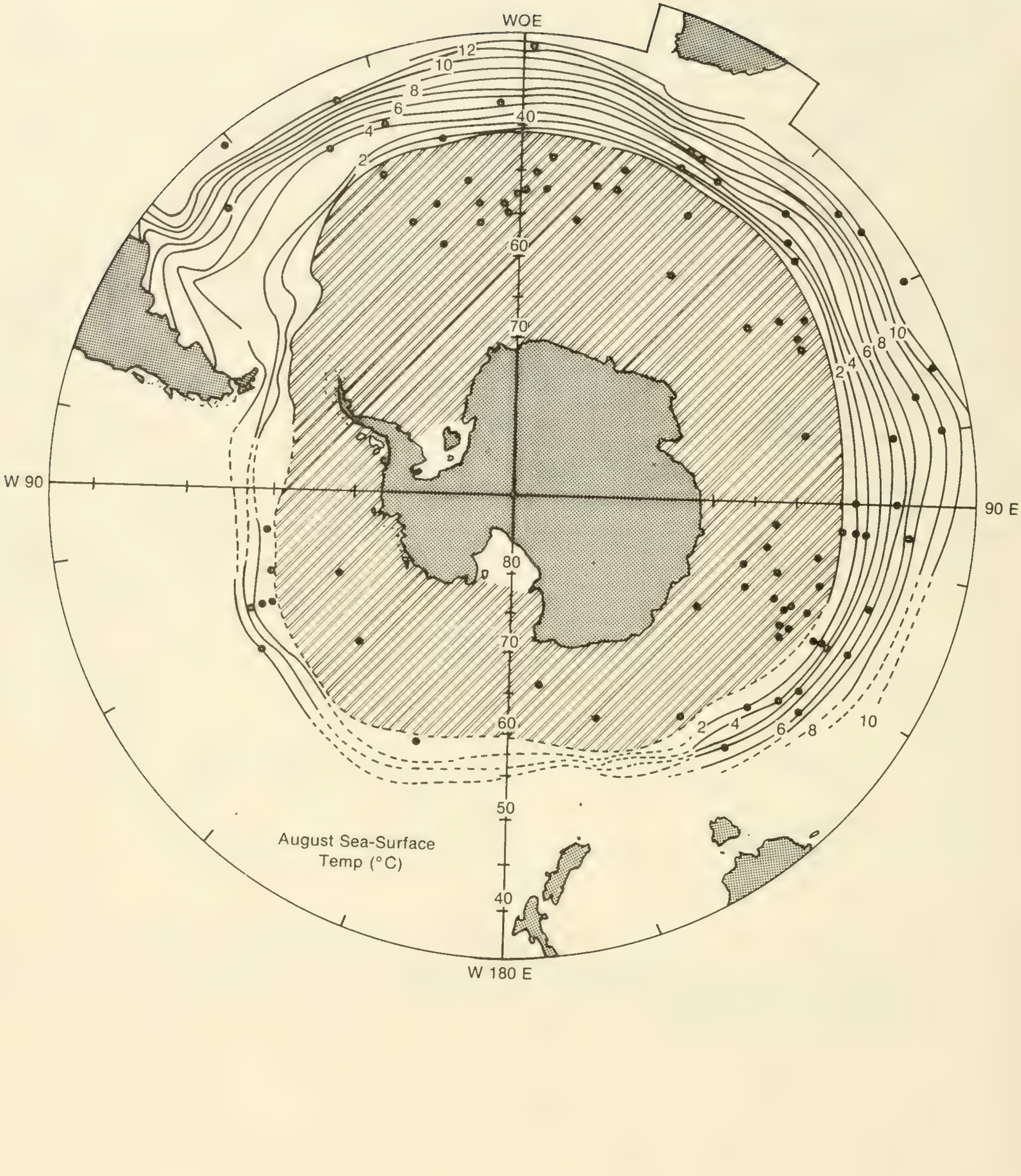


Figure 35.—Estimate of winter sea-surface temperatures north of the estimated ice limit 18,000 years B.P.

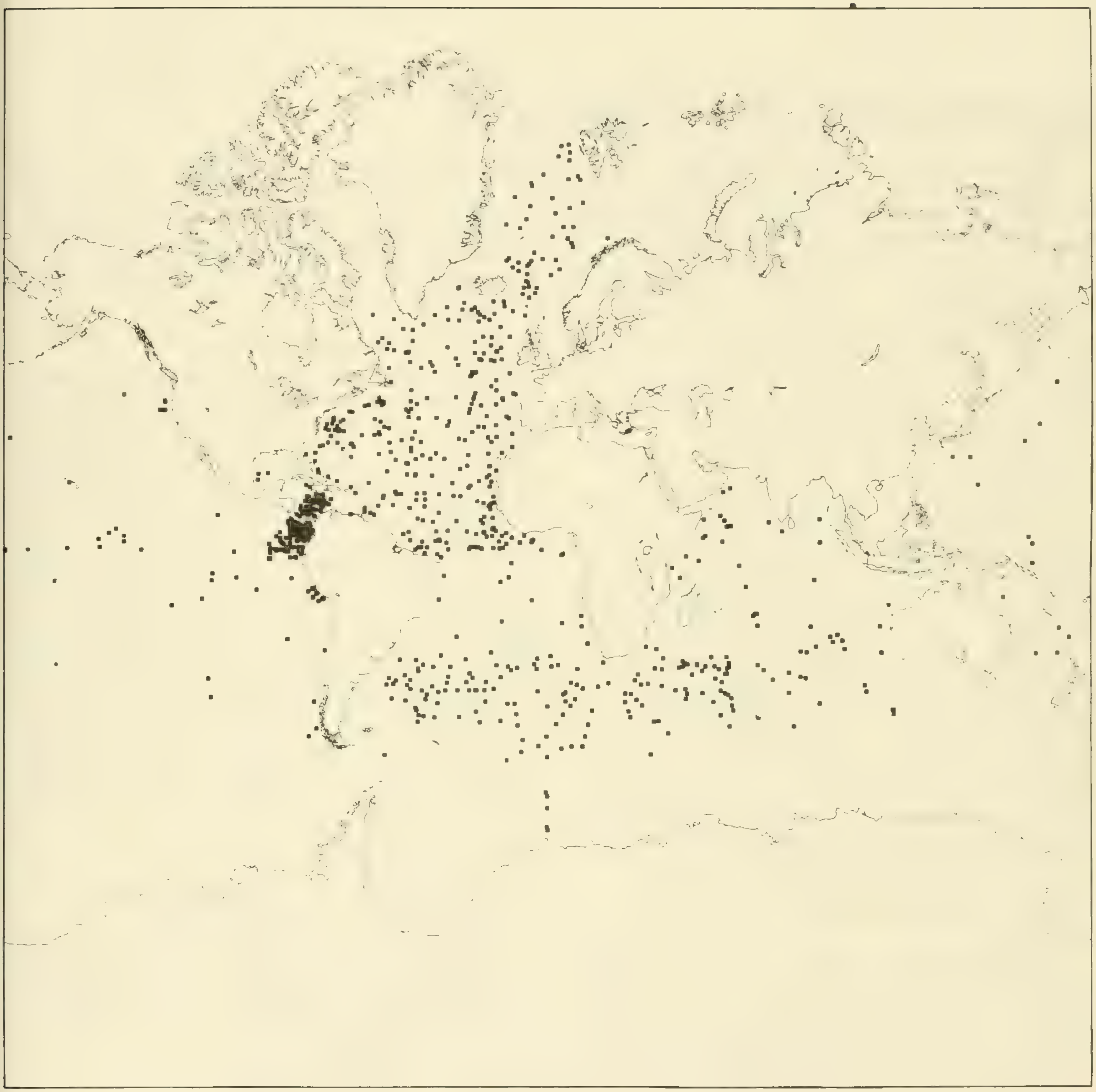


Figure 36.—Sampling locations of 934 cores collected for CLIMAP.

Seabed Assessment Program

This program funds basic research that focuses on the geological processes along continental margins, midocean ridges, and deep-sea basins. In the last decade, Earth scientists began to recognize the subtle relationship between the movements of the Earth's crust and the active processes in the world's oceans and their bearing on the origin and development of hydrocarbon and metallic ore deposits.

The projects supported by Seabed Assessment are broadly grouped as Continental Margin Studies, Plate Tectonics and Metallogenesis, and the Manganese Nodule Program. Projects currently supported include:

1. Southwest Atlantic Continental Margin
2. Galapagos Rift Hydrothermal Processes
3. Nazca Plate Study
4. Studies in East Asia Tectonics and Resources (SEATAR)
5. Manganese Nodule Program (MANOP)

Projects of this large a scale require cooperation among several institutions, disciplines, and nations.

Once IDOE accepts a project it is supported for 4 years to 8 or 9 years. Support typically includes dedicated ships and the development of new technology.

The project usually requires three phases: synthesis of available data, field programs for the acquisition of new data, and finally, synthesis and publication of results. More than one topic may be investigated in the same geographic area, and conversely, one topic can be investigated in different ocean environments. For example, the Nazca Plate and SEATAR projects address the plate tectonic cycle from spreading center, plate movement, metallogenesis, and hydrocarbons genesis. In MANOP, the processes of manganese nodule origin and distribution are studied in various ocean environments.

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Continental Margin Studies

The continental margin is being studied to better understand the rifting of continental land masses and the effects of the rifting on the margins. Continental margins are broadly divided between passive (pull-apart) and active (compressive) types. The margins around the Atlantic are almost all passive; those around the Pacific are active. At the beginning of the decade, knowledge of the origin and structure of margins was poorly known and very uneven.

Southwest Atlantic Continental Margin

IDOE supported major investigations of the passive margins around the South Atlantic and active margins off western South America and in East Asia. Field studies off the coast of Argentina and Brazil were completed in 1976. Results are available in two sets of comprehensive geophysical and bathymetric maps issued by the American Association of Petroleum Geologists (AAPG), Box 979, Tulsa, OK 74101. One set of maps covers the continental margins of Argentina; the other, the margins of Brazil. (See fig. 37.) Each set includes four maps: bathymetry, sediment isopach, gravity, and magnetics, all at a scale of 1 inch equals 1 degree of longitude. In addition, all maps include an interpretational text, sources of data, and data-gathering techniques. These results provided a substantial data base for selection of drifting sites on International Program of Ocean Drilling (IPOD) Legs 36, 37, 39, 40, 41, and 42.

Detailed studies on the interrelationship between sedimentation and structure of the Brazilian continental margin, especially the Amazon cone, have been completed through cooperative studies by Woods Hole Oceanographic Institution and Brazilian scientists. (See table 10.)

Continental Margin Data

Continental Margin data received during the period of this report are available from NGSDC as follows:

University of Texas at Galveston—J. Watkins, 150 nmi of multichannel (24-track) seismic data profiles on mylar base.

University of Texas at Galveston—J. Watkins 1,510 nmi of digital navigation for multichannel seismic data collected in the Gulf of Mexico.

Continental Margin Bibliography

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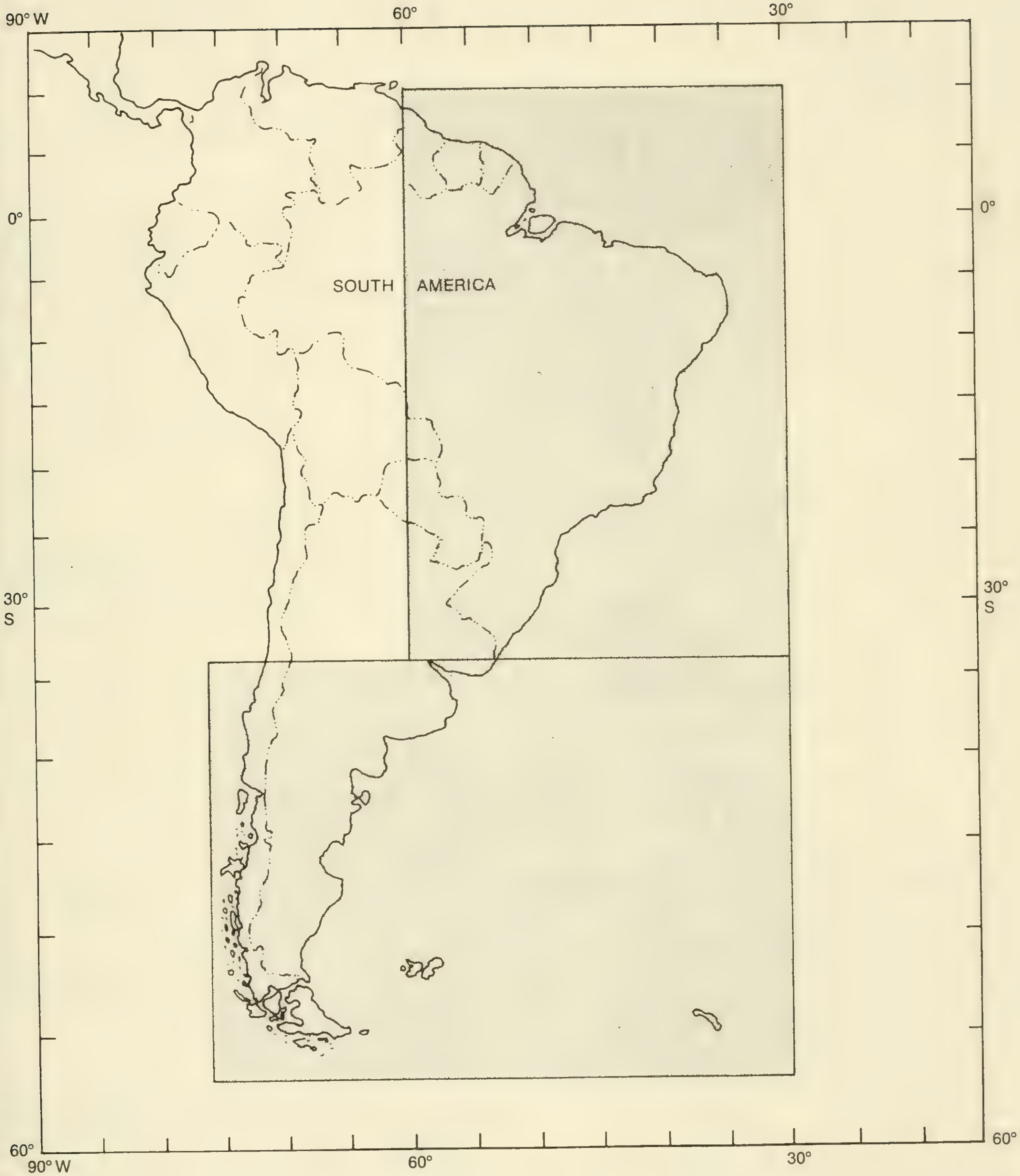

Figure 37.—Areas of coverage for the American Association of Petroleum Geologists map sets of the Brazilian (top) and Argentinian (bottom) continental margins.

Table 10.—U.S. institutions, investigators, and projects in Southwest Atlantic Continental Margin Study

Institutions	Investigators	Projects
Lamont-Doherty Geological Observatory	G. M. Bryan	Geophysical Study of the Continental Margins of Brazil and Argentina
	I. W. D. Dalziel	Evolution of Margins in the Scotia Sea
	J. E. Damuth and N. Kumar	Amazon Cone: Morphology, sediments, age and growth Pattern
		Sedimentation Along Northeast Brazil Continental Margins
	M. A. Gorini	Tectonic Fabric of Equatorial Atlantic and Adjoining Continental Margins: Gulf of Guinea to Northeast Brazil
	N. Kumar	Origin and Geologic History of Sao Paulo Plateau (Southeastern Brazil Margin)
		Origin and Evolution of Ceara Rise (west equatorial Atlantic)
	W. Ludwig	Sedimentary Basins of Argentine Margins
	R. Leyden	Salt Diapirs Offshore Brazil
	P. Rabinowitz	Mesozoic South Atlantic and Evolution of its Continental Margins
Woods Hole Oceanographic Institution	J. D. Milliman and C. P. Summerhayes	Upper Continental Margin Sedimentation off Brazil
	J. D. Milliman	Structure and History of three Continental Margin Plateaus off Brazil (Pernambuco, Rio Grande Du Norte, and Ceara)
	J. D. Milliman and R. Fainstein	Morphology and Structure of the Amazon Margin

eastern South American margin. Geol. Soc. Am. Bull. 88: 720–722.

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Plate Tectonics and Metallogenesis

A fuller understanding of the origin and development of ore deposits is needed to guide the search for new reserves of minerals vital to industrial civilization. One of the significant implications of plate tectonic theory is that active processes along plate margins relate in subtle ways to the formation both of economic metal deposits and hydrocarbon accumulation. The subject is a complex, multifaceted one that includes both seafloor- and mountain-building processes. The circum-Pacific belt, characterized by active subduction zones, parallels to varying degrees some of the world's major metallogenic provinces. At one end of the system, hydrothermal processes along the spreading centers of the ocean floor show evidence of metal concentrations, and at the other end in the mountain belts, suites of rocks in the zones of metal accumulation suggest deep marine origin. Following the paths of the metals from the source to the mine is a major scientific problem in Earth science that the Seabed Assessment Program is supporting in part through several projects.

Studies of the western boundary of the Nazca Plate and the Galapagos Hydrothermal Rift are major efforts to understand the processes of crustal formation and metalliferous sediment accumulation. The back-arc basins, until now largely uninvestigated, are also possible sources of new crustal material. The latter are situated along the Mariana-Philippine Transect of the SEATAR project (Studies in East Asia Tectonics and Resources).

Correlation of processes along the active subducting margins with the final cumulative products within the folded mountain belts is a current major geological problem. The study processes

of ore formation are encompassed within this larger problem. These processes are investigated from the seaward side along the Peru-Chile Trench, which forms the east boundary of the Nazca Plate and also parallels the major copper deposits of Peru and Chile.

The major Transects in the SEATAR area are the Sunda, Banda, and Mariana-Philippine cross active subduction zones and areas of significant minerals and hydrocarbons accumulation.

Galapagos Rift Hydrothermal Processes

The Galapagos Rift, an active spreading center that forms the boundary between the Cocos Plate on the north and the Nazca Plate on the south, is the site of hot springs on the deep-sea floor produced by convective circulation of seawater through newly formed oceanic crust. This conclusion was drawn by a group of U.S. scientists who investigated this area using a number of methods culminating in a program of deep diving by the manned submersible, ALVIN. (For a list of projects, see table 11.) For several years, surface ship investigations of deep-sea rocks, heat-flow patterns near spreading centers, and metal-rich sediments, all suggested that these seawater hydrothermal systems might be a previously unsuspected process of great importance in controlling the composition of seawater and deep-sea deposits. In addition, there was increasing evidence that a variety of economically important metal deposits on the continents are produced directly or indirectly by this process.

A joint research effort of scientists from Oregon State University (OSU), Woods Hole Oceanographic Institution (WHOI), U.S. Geological Survey (USGS), Massachusetts Institute of Technology (MIT), and Scripps Institution of Oceanography (SIO) was funded in 1976. The project was conceived as a broad study of the phenomena related to hydrothermal activity.

A preliminary study of $10 mi^2$ identified the most promising areas for investigating hydrothermal activity. The submersible work was successfully completed in March 1977 during two 20-day legs as indicated from the following list of accomplishments:

1) The first direct observation of deep-sea hydrothermal vents was made. Four major hydrothermal areas were discovered, each containing many individual vents. Three extinct vent areas were also found.

2) Direct temperature measurements from these vents indicate that water as much as 15°C warmer than bottom water is issuing from the bottom at the spreading center.

3) A data acquisition system using the GEOSECS Conductivity/Temperature/Depth (CTD) package and data logger was developed for ALVIN, which could continuously measure and record in situ oxygen, pH, salinity, and temperature of the hydrothermal vents. This package also recorded altitude, depth, gyro, and time from the submarine.

4) Continuous temperature measurements were recorded at one vent for about 10 days.

5) Eighty-eight 8-1 samples of water were collected from and around the vents, using a newly developed contamination-free sampling system. Literally thousands of subsamples were taken for isotopic and chemical shore-based analyses.

6) These water samples were analyzed while at sea for alkalinity, ammonia, calcium, chlorinity, hydrogen, hydrogen sulfide, magnesium, nitrates, nitrites, oxygen, pH, phosphates, radon-222, salinity, and silicon, providing real-time data for guiding the sampling program.

Table 11.—U.S. institutions, investigators, and projects in the Galapagos Rift Hydrothermal Processes Study

Institutions	Investigators	Projects
School of Oceanography, Oregon State University	J. Corliss	Solid Phase Studies: Chemical and Mineralogic Studies of Suspended Particulate Material Metal Rich Sediments, Manganese Crusts, and Basalt Samples
Massachusetts Institute of Technology	J. Edmond	Chemical Study of Hydrothermal Fluids
Woods Hole Oceanographic Institution	R. P. Von Herzen	Heat Flow Studies
	R. Ballard	Geologic Structure and Tectonic History of Galapagos Spreading Center
Stanford University	Tj. vanAndel	Geologic Structure and Tectonic History of Galapagos Spreading Center
U.S. Geological Survey	D. Williams	Heat Flow Studies

7) The ANGUS camera system made a highly detailed photographic survey of the study area using over 57,000 individual frames to pinpoint the geological and tectonic setting of the vent areas. This film was processed shipboard and helped to guide the diving program.

8) One hundred and sixty navigated heat-flow stations from the RV KNORR and 35 stations from the ALVIN were conducted to quantify the thermal budget in the study area.

9) Unique communities of organisms (clams, crabs, limpets, mussels, pogonophora worms, etc.) were discovered around the hot water vents. Sulfide-oxidizing bacteria are believed to be the basis of the food chain in these communities.

10) A collection of organisms, water for bacterial analysis, and ANGUS and ALVIN photographs was made that will be the basis for detailed biological studies of these unique communities.

11) ALVIN collected 92 samples of fresh basalt, hydrothermally altered basalt, iron-manganese crusts and coatings, and cores in known geological relation to the hydrothermal vents and the general geologic setting.

12) Thirty-four samples of newly forming precipitates were collected near the hydrothermal vents using a water-filter system developed for use on ALVIN.

13) Ten cores up to 9 m long were obtained directly from the hydrothermally formed sediment mounds south of the spreading center using transponder-navigated piston coring.

14) Heat-flow measurements from these piston cores indicate that nearly isothermal pore waters up to 12°C are found in the upper portions of these mounds.

15) In situ pore-water sampling from piston cores and shipboard squeezing of sediments obtained samples of the fluids that are apparently connecting through the sediments at the Fe-Mn mounds area.

16) ALVIN successfully recovered three sediment traps, which had been deployed at two sites in the study area and provide a 7-month record of particle flux to the sea floor.

17) Eight hydrocasts and seven acoustically navigated Kamikaze near-bottom casts were made to characterize the regional variability and water-column chemistry of the sea.

18) During the 24 dives made by ALVIN, over 18,000 color photographs by the automatic cameras of the submersible and 2,000 hand-held photographs were collected and developed on ship to document and guide the diving program.

19) Near-bottom water temperatures were monitored during ANGUS camera runs and Kamikaze casts as a reconnaissance tool for discovering new vent areas and as a means for obtaining data on regional bottom water temperature.

20) Near-bottom CTD surveys (5-50 m off the bottom) were made over different vent areas to obtain the three dimensional thermal structure of the thermal plumes.

The accomplishments of the diving expedition provide an extensive set of unique samples and data. Analysis is underway; however, several initial results can be reported:

1) The hydrothermal fluids contain hydrogen sulfide. This leads to extremely low concentrations of cadmium, copper, iron, nickel, and zinc, presumably because they precipitate as stable sulfides. Thus, the thermal springs of the Galapagos Rift are not presently supplying these elements to the ocean. The data indicate that ridge crest hydrothermal systems are clearly a major source of manganese and a major sink for magnesium in the oceans. The linear silicon-temperature relationship in the samples suggests that the fluids sampled are mixtures of normal bottom water and an end-member hydrothermal fluid that interacts with the rocks at depth at temperatures around 300°C. The helium-3 flux from the springs can be used to quantify the global thermal flux of these midocean ridge hydrothermal systems, and the estimate is similar to previous estimates based on heat-flow data.

2) The heat-flow observations clearly support the notion that convective heat loss by hydrothermal circulation, most intense at the ridge axis, is a fundamental process cooling the Earth. The mean heat flow in the region, from over 400 stations, is 7 heat flow units, which is about one-third of the value predicted by the purely conductive model. This suggests that two-thirds of the heat entering the ocean at the midocean ridges is transferred by hydrothermal processes. To improve these estimates, the detailed maps of the plumes will be used to estimate the actual flux of heat from the thermal springs.

3) The extensive photographic survey of the area with the ANGUS system has produced a geologic map of the area in which five distinctive basalt types can be defined, based on their morphology and relative ages deduced from sediment cores. In addition, features such as fissures, eruption centers, collapse structures, and faults have been accurately mapped. Petrochemical studies of the rocks sampled from ALVIN will supplement these studies.

4) The biological communities associated with the vents have received careful study. Maps of the distribution of animals of each vent have been produced from ANGUS photographic surveys. Taxonomists have studied the animal specimens; new species, genera, and families will be defined. The microbiology of the vent areas is unique; high concentrations of sulfur-oxidizing bacteria are present in the water and animals, and laboratory measurements of productivity suggest that these organisms could support the large animal populations found at the vents. *This leads to a major biological discovery—these animal communities are the first known to derive their energy entirely from geothermal heat, and are thus independent of photosynthesis.*

This preliminary work is continuing, and numerous publications are planned or are in preparation. These results will have far-reaching implications in the understanding of the history of seawater, the formation of deep-sea sediments, the nature and evolution of life in the deep sea, the formation of ore deposits, and the possible importance of submarine geothermal systems as an energy resource.

In situ photo of Galapagos Rift hydrothermal vent. First hand evidence of hydrothermal plume. Fluids contain H_2S.

Nazca Plate Study

The Nazca Lithospheric Plate lies adjacent to the event edge of the great metallogenesis province of the Andes. This area was the subject of major field programs from 1972–75 by Oregon State University and the Hawaiian Institute of Geophysics in cooperation with scientists from Chile, Columbia, Peru, and Ecuador. (For a list of projects, see table 12.) The results were synthesized into comprehensive models of the Nazca Plate that served as site surveys for subsequent drilling on Offshore Drilling Project (OSDP) Leg 34 by the GLOMAR CHALLENGER. Three holes were drilled through the sedimentary sequence into basement rocks, one in the Bauer Basin (metalliferous sediments) and two on the seawater side of the Peru-Chile Trench.

Based on seismic refraction velocities, the western edge of the plate has a relatively thin ocean crust thickening to 30 km near the trench. Oceanic magnetic anomaly patterns make it possible to follow the history of plate origin and movement during the past 26 million years. The information obtained here is expected to be applicable to understanding the process along subduction zones around the circum-Pacific belt.

Sediments on the Nazca Plate are derived from four sources: 1) hydrothermal (direct precipitation from seawater hydrothermal systems); 2) biogenous; 3) detrital (weathering and erosion of crustal rocks); 4) hydrogenous (precipitation from normal bottom waters). Most metalliferous sediments were deposited by hydrothermal fluids emanating from sources of basaltic magmatism along the East Pacific Rise (EPR). Deposition, however, took place in normal low temperature seawater.

Analysis of the sedimentary sequence cored at Deep Sea Drilling Project Site 319 (Leg 34) in the Bauer Basin shows a change in composition through time parallel to the changes in surface sediments, as one moves from west to east across the Nazca Plate. Metal accumulations are highest near the basement layer, suggesting strong hydrothermal contribution during the early history of this site. Abundant manganese nodules and crusts were also recovered from the Bauer Basin. Analysis shows a distinct mineralogical and chemical difference between them. Normal precipitation from seawater controls the mineralogy and chemistry of the crusts, while that of the nodules appears to be governed by small-scale reactions in the underlying sediments. The presence of biogenic opal appears to be a critical factor in nodule formation; a factor that should be useful in explaining concentration of nodules in other areas of the sea floor.

Study of formation of large grabens in the Chile Trench, a result of bending of the Nazca Plate, may explain the tectonic erosion of sections of the Chile continental margins. Other evidence suggests that the bending has produced rapid tectonic uplift along the trench axis. A detailed set of bathymetric maps of the Peru-Chile Trench, including all the data collected during the Nazca Plate project, was completed and has been accepted for publication by the Geological Society of America. The maps synthesize the results of this project, are in the final stages of editing, and are scheduled for publication late in 1978.

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Table 12.—U.S. institutions, investigators, and projects in the Nazca Plate Study

Institutions	Investigators	Projects
University of California, San Diego, Scripps Institution of Oceanography	J. Mammerickx	Bathymetry of the Nazca Plate
University of Hawaii, Hawaii Institute of Geophysics	G. Woolard	Gravity and Crustal Structure of the Nazca Plate
	D. M. Hussong	Crustal Studies of Nazca Plate and Its Margins Sediment Isopach Map of Nazca Plate
	M. E. Odegard	Acoustic Properties of Metalliferous Sediments
	R. Moberly, G. Shepherd, W. C. Coulbourn, and S. Johnson	Evolution of Fore-Arc Basins off South America
	J. Resig	Paleobathymetry, paleoecology, and derivation of Sediments on the Nazca Plate
	R. Hey	Plate Tectonics and Discontinuities Along the West Margin of Chile
		Tectonic Evolution of Cocos-Nazca Spreading Center
	K. E. Handschumacher	Post Eocene Tectonics of Eastern Pacific Based on Magnetic Anomalies
	J. Rose and T. R. Getts	Gravity and Tectonics of Eastern Nazca Plate and Peru Chile Trench
	H. Veeh and G. McMurtry	Metalliferous Sediment Accumulation on the Nazca Plate
	C. Fein	Chemical Investigation of Nazca Plate Basalts
Oregon State University, School of Oceanography	L. Kulm and W. Schweller	Crustal Structure and Tectonics of the Peru-Chile Trench
	J. Dymond and J. Corliss	Metalliferous Sedimentation on the Nazca Plate
	J. Dasch	Isotope Studies of Metalliferous Sediments and Deep Sea Basalts
	C. W. Field	Magmatism and Metallogeny of the Andean Cordillera
	K. E. Scheidegger and J. Corliss	Study of Basalts from Peru-Chile Trench and East Pacific Rise
	D. K. Rea	Magnetic and Structural Studies of the East Pacific Rise
	R. Couch	Gravity and Crustal Structure of the Nazca Plate

Studies in East Asia Tectonics and Resources (SEATAR)

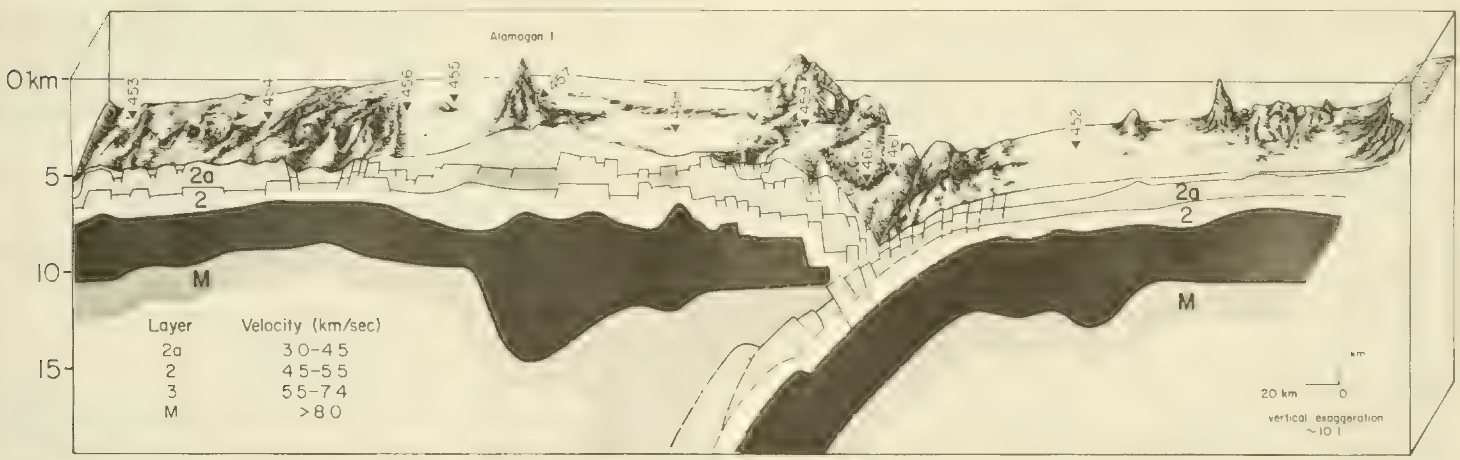
An international group of scientists are performing a large-scale, comprehensive investigation of the interplay between the regional tectonics and the occurrences of metals and hydrocarbons in East Asia. Projects are listed in table 13. This project, based on recommendations of a workshop held in Bangkok in 1973, made significant progress in 1977. Major operations, both marine and land, were conducted along the Sunda Arc and Banda Arc and the Philippine Sea. In addition, work on a geophysical atlas of the area has been completed and accepted for publication as part of the Geological Society of America map series. A bathymetric map was published in 1977. The final product, scheduled to be issued later this year, will include gravity, magnetic anomaly, total sediment isopach (based on seismic reflection velocities), crustal structure (seismic refraction velocity distribution), tectonics, and heat flow. A seismotectonic map covering a more limited area (115° E to 130° E and 5° S to 20° N) has been partially completed. A report on the Banda Sea area is in press, and the area of the Moluccas and Philippines is near completion. Two more segments are scheduled: Taiwan-Ryukyu Trench and the Mariana-Philippine Sea. The heat flow cited above was based on existing data. Additional surveys have been made on the island of Sumatra by V. Vacquier (SIO) and in Thailand, Malaysia, and the Philippines by S. Uyeda (Tokyo U). A geothermal gradient map was published in 1977 by the Southeast Asia Petroleum Exploration (SEAPEX) Society using data from oil exploration wells. The result of all these efforts will be the most comprehensive survey of temperature data for an active island arc system.

Curray and Shor (SIO) and Karig (Cornell) completed four legs of a cruise in the area of the Andaman Sea, Java Sea, and Banda Sea. The Scripps multichannel seismic system operated successfully on its first field experience. In this region of thick sediments, the multichannel data provided diagnostic evidence of the interplay between basement tectonics, sea level, and sediment supply. In the Sunda Arc, where the India plate is subducting the China plate, reflection data are obtained from the deep structure of the descending slab and deep structure and sediments in the fore-arc basin. In cooperation with Indonesian scientists, seismic refraction data from two ships were obtained from oceanic crust and mantle. Karig and associates made detailed investigations of the fore-arc sections on the islands offshore of Sumatra. The Scripps group obtained additional geophysical data and geological samples in the Banda Sea to refine the interpretation based on the 1976 cruise. The several participants in this cruise will work together on the analysis of this broad spectrum of data. British, German, and Japanese geologists working on land in Sumatra and field geologists from the oil companies working in Southeast Asia are generously cooperating in a broad effort to unravel the problems of plate tectonics in this area.

On another leg of the Scripps cruise, Eli Silver (UCSD) and R. Raitt (SIO) collected data on seismic reflection and gravity, and extensive bottom samples from the Molucca Sea, which lies north of the Banda Arc and south of Mindanao. Preliminary results indicate that this is a zone of arc-arc collision. Seismic reflection data trace the parallel thrusts and, in combination with bottom samples, confirm the melange nature of the sedimentary section.

The RV Valdivia (Federal Republic of Germany) carried out a broad-scale program of geophysical measurements (including multichannel seismic data) and geological sampling, extending from the Malacca Strait to the Philippines and including the northwest continental margin of Australia, Strait of Makassar, Island of Celebes, Sulu Sea, and Philippine Sea. Lamont completed a geophysical survey of the West Philippine Basin and Luzon margin using 24-channel common depth point (CDP) seismic reflection techniques and complementary geophysical measurements. These large-scale data gathering efforts were made jointly in support of the SEATAR and IPOD site surveys.

In 1978, IDOE will support a major program to study the tectonics and evolutionary history of the marginal basins and the island-arc-trench systems along the Mariana-Philippine Transect. The areas of focus are the Mariana Trough and arc-Trench plus selected portions of the Parece Vela and west Philippine Basins. Both shipboard field work and land-based programs in selected portions of the Marianas are scheduled.



Generalized E-W crustal section across Mariana Island Arc subduction zone at latitude 18°N, including locations of drilling sites from DSDP Leg 60. Bathymetry drawn by W. Coulbourn based on data from Hawaii Institute of Geophysics (HIG) 1976 cruise. Crustal structure generalized by D. Hussong from HIG seismic refraction, reflection, and gravity data collected in 1976 and 1977.

The proposed program is aware of Legs 59 and 60 to be drilled in early 1978 (fig. 38). Standard geophysical measurements, geological sampling, and magnetotelluric measurements will be made. An extensive array of ocean-bottom and land-based seismometers will be deployed. In addition to recording the seismicity of the area, explosive charges will be used to obtain precise velocity data.

The Mariana-Philippine Transect is the fifth of the six tran-

Table 13.—U.S. institutions, investigators, and projects in SEATAR

Institutions	Investigators	Projects
Lamont-Doherty Geological Observatory	D. E. Hayes	S. E. Asia Marine Geology and Geophysics Program
		Steering Committee Support
		The Parece Vela and West Philippine Basin Studies
		Program Coordination
	R. Anderson, E. Bonatti, and J. Lawrence	Heat Flow, Metallogenesis, and Sea Water Convection in the Oceanic Crust
	E. Bonatti	Philippine Ophiolites
University of California, San Diego, Scripps Institution of Oceanography	J. W. Hawkins	Evolution of Oceanic Crust Geochemical and Petrological Studies, Mariana Trough and N. Luzon Trench
	G. G. Shor, Jr.	Seismic Refraction Studies of the Mariana Arc and Trench
		Seismic Refraction Banda Arc
		Marine Geology and Geophysics of the Sunda Arc
	J. Curray	Marine Geology and Geophysics of the Andaman Sea
	J. H. Filloux	Magnetotelluric Traverse Across-Mariana Trench, Arc, and Trough
	L. Dorman	Seismicity and Seismic Refraction of the Mariana Trough and Arc-Trench Areas
	J. Mammerickx	Bathymetry of East Asian Seas
Cornell University	D. E. Karig	Characteristics and Evolution of Back-arc spreading in the Mariana Trough.
		Nias/Sunda Transect
	B. Isacks	Seismological Studies of the SEATAR Area (Banda, Sunda, and the Philippine Sea Plate).
		Operation of Temporary Seismograph Network on the Mariana Islands
	R. Kay	Magma Genesis in Back Arc Basins (dredged and drilled rocks from Mariana Trough)
University of Hawaii, Hawaii Institute of Geophysics	D. Hussong	Distribution of Earthquakes, Epicenters, and some Focal Mechanisms in Diverging Basins
University of Texas, Galveston, Marine Science Institute	G. Latham	Ocean Bottom Seismometer Observation, Mariana Transect
University of California, Santa Barbara	M. Reichle	Seismicity and Seismic Refraction of the Mariana Trough and Arc Trench Areas
University of Arizona	A. Meijer	Geochemical, Petrologic (Pb and Strontium Isotopes) Studies of Volcanic Islands, Dredge Samples from Mariana Back-arc Basins
Colorado School of Mines	A. Divis	Magmatic Processes in Evolution of Arc Copper-Molybdenum Deposits
Woods Hole Oceanographic Institution	C. O. Bowin	Banda Arc Geophysical Studies

sects recommended by the Bangkok workshop (1973). Work on the sixth (Japan-Korea transect) was largely the responsibility of these respective countries. In an effort to assess the results to date and to plan a program of research for the balance of the decade, a special SEATAR Workshop will be held in Jakarta, Indonesia, Oct. 17 to 21, 1978, prior to the 15th session of the Committee for Coordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas scheduled for Singapore, Oct. 24 to Nov. 4, 1978.

SEATAR Data

SEATAR data received during the period of this report are available from NGSDC as follows:

Scripps Institution of Oceanography—G. Shor, 3,770 nmi of seismic reflection data on 35 mm microfilm.

Woods Hole Oceanographic Institution—C. Bowin, 3,451 nmi of seismic reflection data on 35 mm microfilm, 8,000 nmi of magnetic data on magnetic tape.

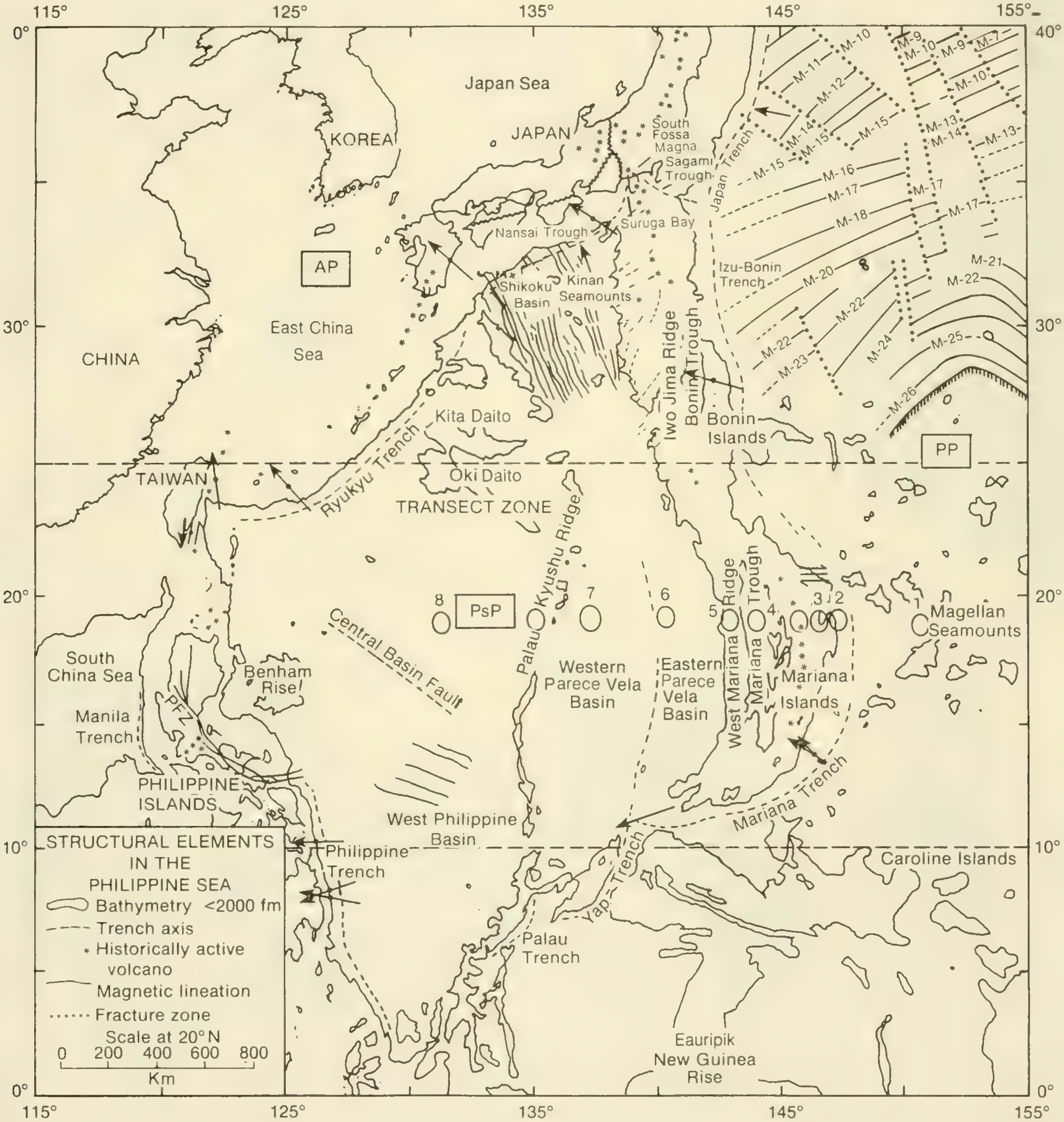
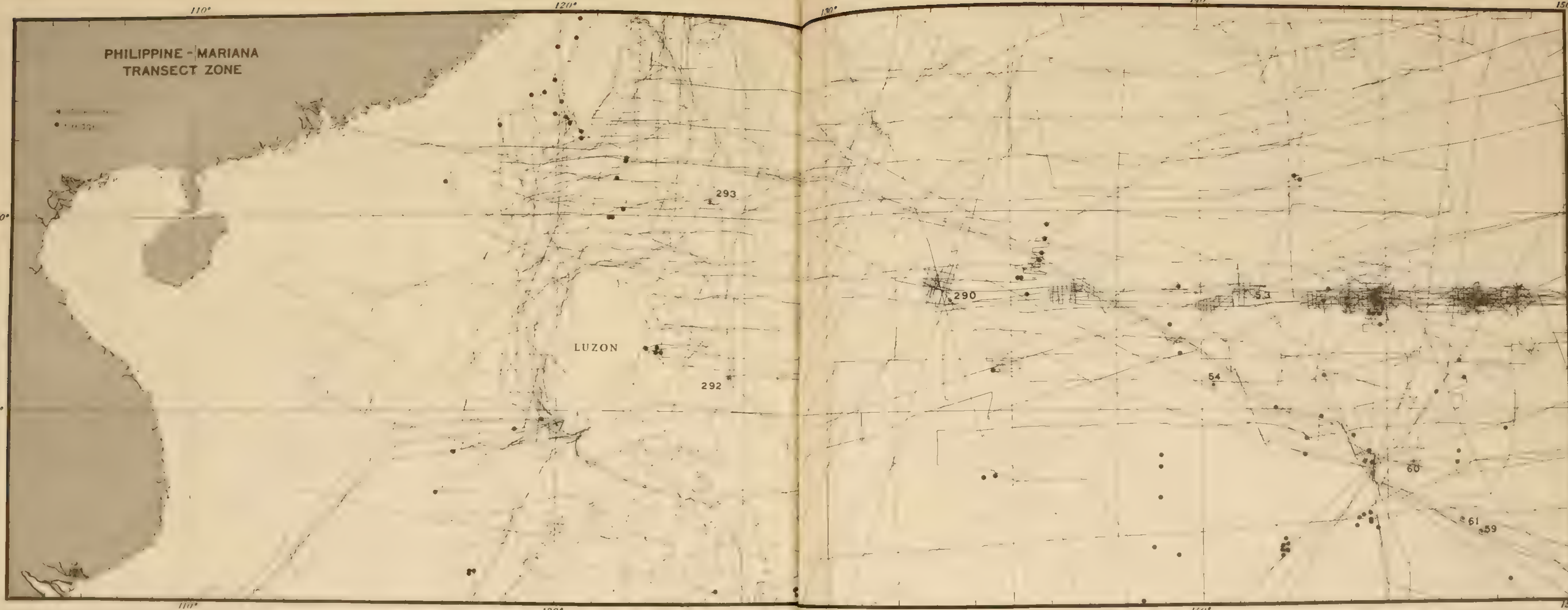


Figure 38.—Structural elements of the Philippine Sea. The inferred direction of relative motion between the Asian (AP) and Pacific (PP) plates and between the Asian and Philippine Sea (PsP) plates are indicated by solid arrows. Taken from Watts and Weissel (1975). IPOD Legs 59 and 60 indicated by sites 1 thru 8.



Locations of all SEATAR data collected within the Philippine-Mariana Transect Zone during the past 15 years. Geophysical track lines, Deep Sea Drilling Project coring sites, and dredge locations are shown.

Manganese Nodule Program (MANOP)

IDOE-sponsored studies of deep-sea manganese nodules changed focus in 1977 with the initiation of MANOP (the new Manganese Nodule Program). Its predecessor programs successively compiled unpublished data on distribution and composition of nodules, and surveyed and sampled a number of small areas within the band of copper- and nickel-rich nodules south and east of Hawaii (fig. 39). MANOP is concentrating on the paths and mechanisms that carry economically important elements, such as copper and nickel, to the sea floor and lead to their incorporation in the nodules. Projects are listed in table 14.

The first approach is to measure all the metal fluxes to a given site on the abyssal sea floor. Sediment traps moored in the water column will record the rate of input from the falling remains of shallow-living plants and animals. The rate of supply of dissolved metals from near-bottom waters will be estimated from detailed profiles of chemical analyses of water samples. A sophisticated Bottom Lander (fig. 40) will measure the release and uptake of dissolved metals at the sea floor. By comparing the Lander values with metal concentrations in pore waters extracted from sediment cores or in situ pore-water samplers, it will be possible to determine what fraction of the metals is derived from upward migration through the sediments and what fraction is released by the dissolution or decomposition of particles recently deposited on the sea floor. The fluxes of metals into nodules and sediments will be estimated from radiometrically determined rates of accumulation combined with chemical analyses of various components of the solid phases. The comparison of flux values in areas of metal-rich nodules with values in areas of metal-poor or no nodules will establish whether the supply of metals or the growth mechanism is primarily responsible for the development of economically attractive nodules.

The second approach is experimental. The Bottom Lander will be used to measure metal-release rates in both enclosed, but undisturbed, nodule-sediment patches and in enclosed adjacent patches, which will be treated with a mixture of antibiotics

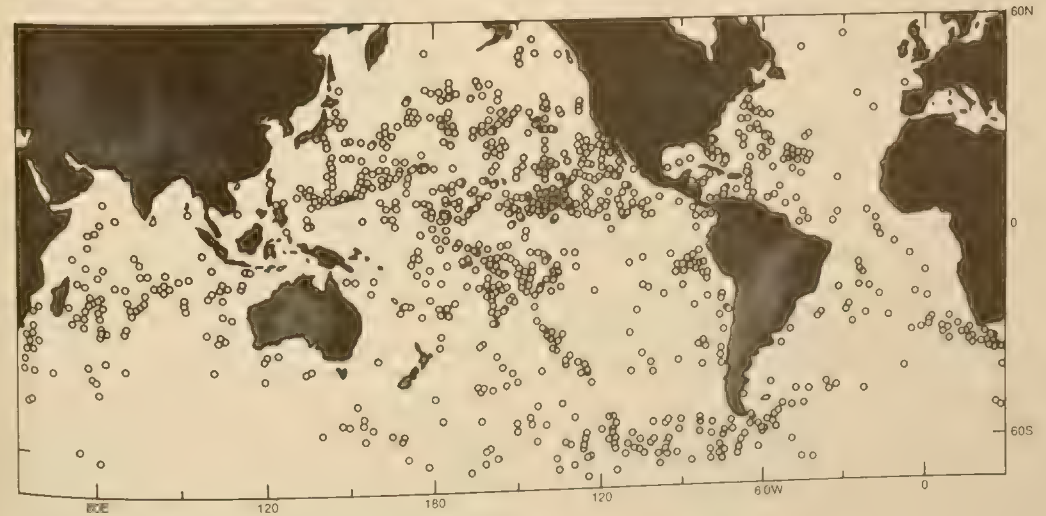


Figure 39.—Nodule distribution map.

Table 14.—U.S. institutions, investigators, and projects in MANOP

Institutions	Investigators	Projects
University of California, San Diego, Scripps Institution of Oceanography	R. Weiss	Bottom Ocean Monitor
	W. Berger, M. Kastner, and J. M. Gieskes	Particle Flux to the Sea Floor Interstitial Water Studies by an In Situ Probe
	J. Greenslate	The Fractionation of Elements Between Various Sediment Components
	J. Macdougall	Manganese Nodule Growth Rates
	F. Spiess and P. Lonsdale	Fine Scale Patterns of Manganese Nodule Distribution
University of Rhode Island Graduate School of Oceanography	M. Bender	Trace Metals and Nutrient Geochemistry in Pore Waters and Bottom Waters
	G. R. Heath	Program Administration
		Studies of Processes Controlling the Composition and Distribution of Deep-Sea Ferromanganese Nodules, 'Labile' and 'Fixed' Transition Metals in Near Surface Sediments
Columbia University, Lamont-Doherty Geological Observatory	P. Biscaye	Long Term Observations of Manganese Nodule Environments
	W. Broecker	Bottom Chamber and Benthic Flux Experiments
Massachusetts Institute of Technology	R. Burns	Mineralogical Changes in Manganese Nodules Under Hydrostatic Pressures on the Sea Floor
	J. Edmond	Measurements of Dissolved Trace Metals and Other Species in the Water Column over the Project Site
Oregon State University, School of Oceanograhpy	J. Dymond	Particulate Flux to the Sea Floor
University of Southern California	T. Ku	Radiometric Dating of Manganese Nodules' Adjacent Sediment
University of South Carolina	W. Moore	Radiochemical Studies of Manganese Nodule Deposition Processes
University of Washington	S. Emerson	Diagenesis and Diffusion in Interstitial Waters
	J. Murray	An In Situ Adsorption Experiment
University of Wisconsin	C. Bowser	Continuing Studies in Role of Early Sedimentary Diagenesis in Formation of Marine Manganese Nodules
Woods Hole Oceanographic Institution	P. Brewer	Investigation of Metal Ion Uptake on Manganese Nodule Surfaces in Deep Ocean

to kill manganese-fixing bacteria (fig. 41). Related experiments will involve the addition of trace amounts of dissolved metals to treated and untreated enclosures to determine the rates of metal uptake by nodules and sediments with and without bacterial activity. Similarly, adding bacteria that are antibiotic-resistant and manganese-fixing to a treated enclosure will help establish the relative roles of organic and inorganic reactions in the growth of nodules.

A closely related series of experiments center on the exposure of well-characterized natural and artificial iron and manganese oxyhydroxides to bottom waters for weeks to years. These experiments will establish the patterns and rates of metal uptake or release by the various mineral phases, as well as the nature of any mineralogic changes that result from the low temperatures and high pressures at the sea floor.

A design review of the instrument has been completed and approved for development. It is estimated that construction and testing of the Lander will be completed in mid-1979.

During 1977, detailed surveys of future Bottom Lander sites were made using the Deep-Tow system of the Scripps Institution of Oceanography. (See fig. 42.) The sites, at the crest of the East Pacific Rise and in the Guatemala Basin, will be used for experiments to assess the influence of hydrothermal input and diagenetic remobilization on transition metal fluxes. The 1977 surveys provide the detailed topographic and sediment-distribution information needed to site the Lander deployments and associated sediment sampling. They also mark the start of the in situ mineral exposure experiments (samples will be recalled on long-lived acoustic transponders in about 5 years). Sediment cores collected during the 1977 cruise are being studied intensively by

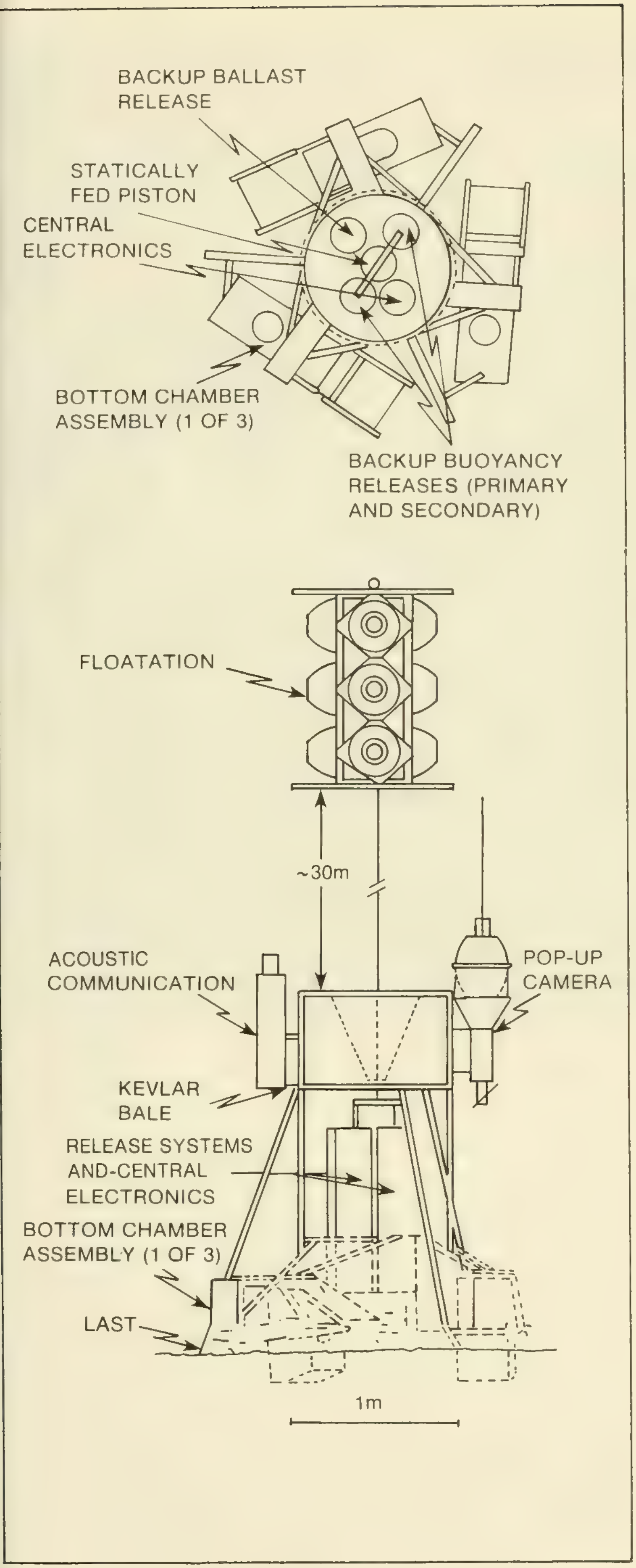


Figure 40.—MANOP Bottom Lander, top and side views. To show the underlying structure, the floatation and Kevlar bale have been omitted from the top view.

pore-water and sediment geochemists. Preliminary results suggest considerable vertical migration of dissolved manganese and iron, as well as other transition metals.

Manganese Nodule Data

Manganese nodule data received during the period of this report are available from NGSDC as follows:

University of Washington, École des Mines—J. Murray, J. Monget, 2,200 chemical analyses of manganese nodules on magnetic tape.

Manganese Nodule Bibliography

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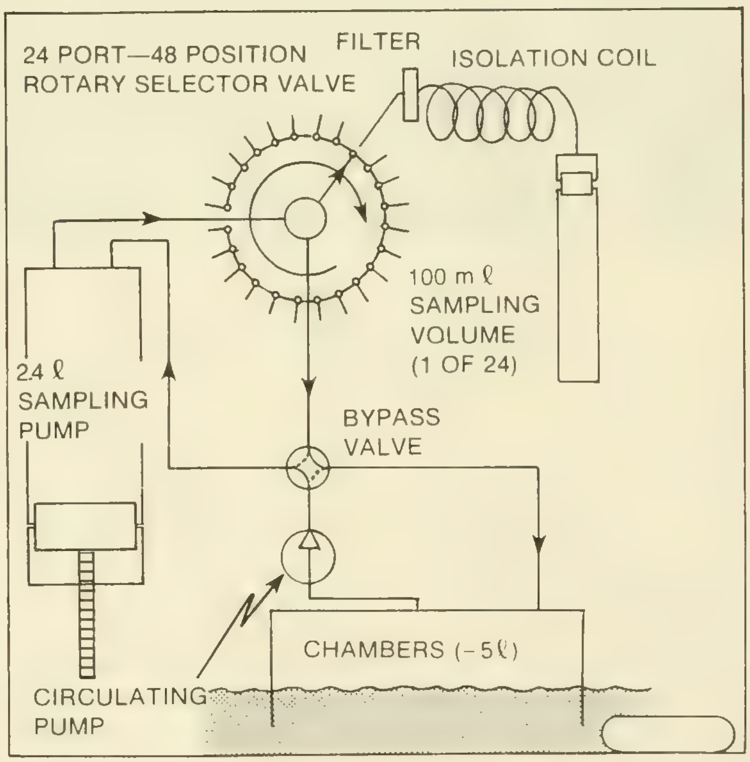


Figure 41.—Water flow diagram for each of the three bottom chamber experiments. All valves and pumps are actuated by stepper motors under microprocessor control. Flow through the 4-way bypass valve in its normal position is shown by the solid lines; dashed lines show the flow through this valve in the bypass position.

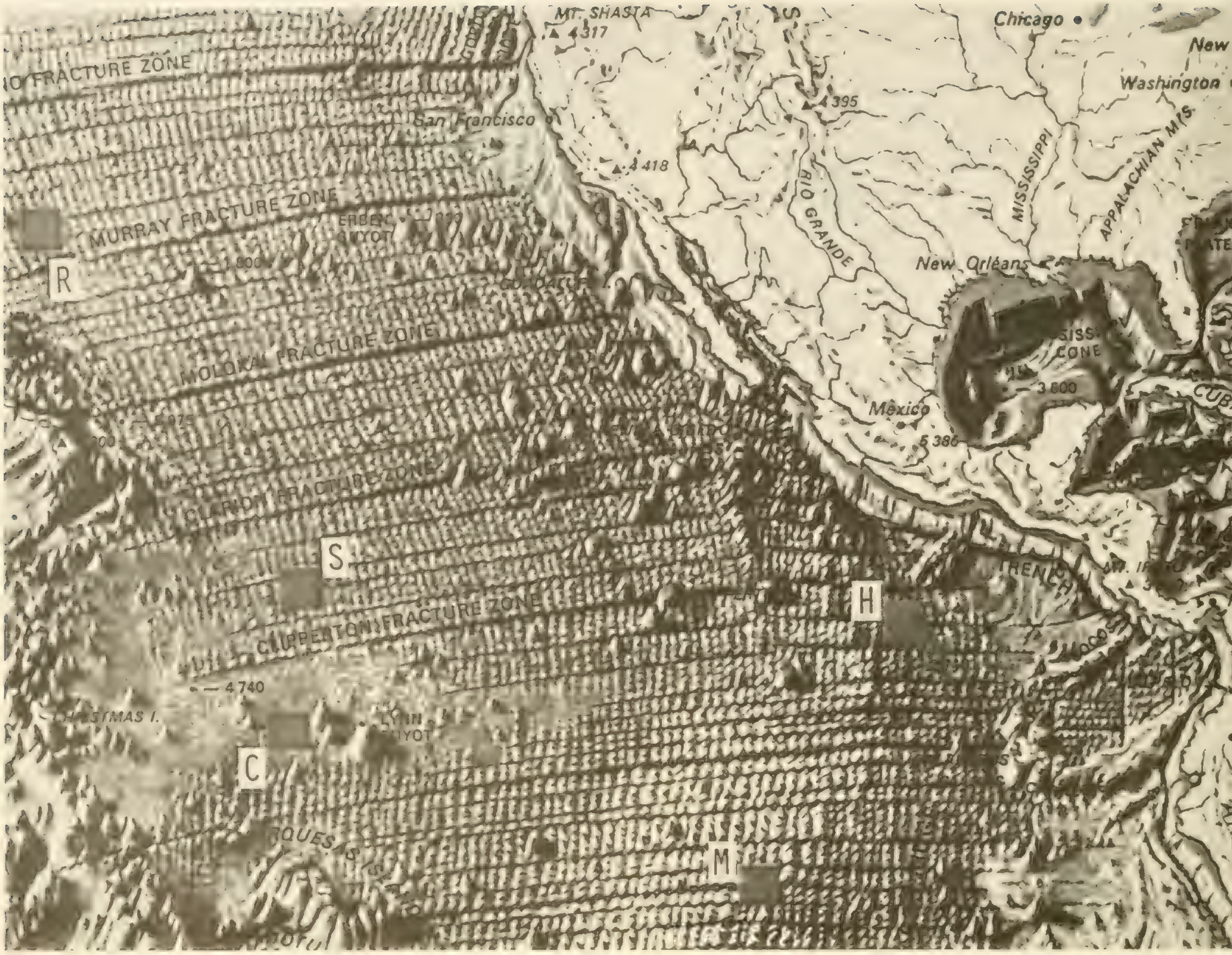


Figure 42.—The lander will be emplaced at five sequential sites for long term monitoring. The sites, each located in a distinct sedimentary environment include: red clay R , siliceous ooze S , calcareous ooze C , metalliferous sediment M , and hemipelagic clay H .

Living Resources Program

The goal of this program is to provide scientific knowledge for improved management and use of the ocean's living resources. Emphasis is on interdisciplinary studies of the mechanisms that produce and sustain marine life. The program includes the Coastal Upwelling Ecosystems Analysis (CUEA) and Seagrass Ecosystem Study (SES) projects.

Coastal Upwelling Ecosystems Analysis (CUEA)

The long-term goal of the CUEA program is to understand coastal upwelling ecosystems well enough to predict their response to changes far enough in advance to be useful to mankind. This goal, when achieved, provides the basis for protecting the long-term productivity of fisheries in these ecosystems. The multidisciplinary CUEA projects are listed in table 15. To achieve its goal, CUEA has four objectives:

1. Describe and understand the mesoscale distributions that define coastal upwelling ecosystems in space and time, including such variables as solar radiation, winds, currents, density, nutrients, phytoplankton, zooplankton, nekton, and benthos, as well as analyses of the spectral characteristics of each.
2. Understand the dynamic processes that affect the total behavior of these ecosystems, and derive quantitative values of wind-induced upper oceanic circulation, mesoscale flow fields, uptake of nutrients by phytoplankton, and other processes that can limit grazing, predation, excretion, respiration, and remineralization.
3. Learn more about the physical, chemical, and biological interactions that increase the production of coastal upwelling ecosystems by an order of magnitude over that of open-ocean areas.
4. Develop models that will simulate the Northwest African and Peruvian upwelling ecosystems to help predict the response of these ecosystems to variabilities in scales and rates of processes, or to different fishery management strategies.

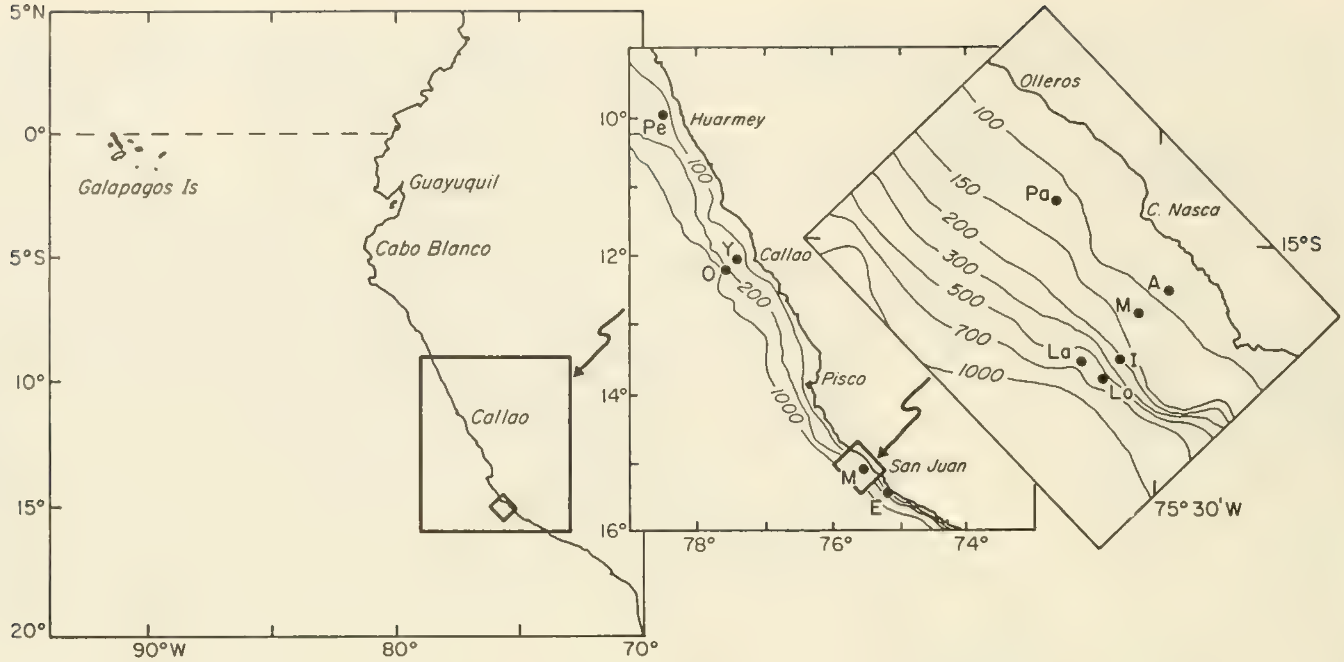
During 1977, the CUEA program completed field work off the coast of Peru and began the analysis and interdisciplinary synthesis of the information that was obtained. The intensive 1977 field effort lasted from March to May and involved an unprecedented concentration of oceanographic facilities. The expedition had shore-based meteorological stations; moored current meter arrays and meteorological stations; four research vessels from the academic fleet, the WECOMA, MELVILLE, ISELIN, and CAYUSE; and an aircraft to map sea-surface temperature and winds.

The scientific objective of concentrating the multidisciplinary analysis on a single geographic region was to obtain a comprehensive view of the physical and biological parameters of the upwelling process. The time-phase diagram (fig. 43) shows the degree to which this objective was achieved in operational and logistic terms. The March through May phase of JOINT-II, an intensive, collaborative study of the Peruvian upwelling ecosystem, was called MAM 77. It succeeded in obtaining a thorough description of the winds, currents, and physical conditions and at the same time showing the biological response to these conditions in terms of phytoplankton species composition, zooplankton abundance and grazing, and fish distribution.

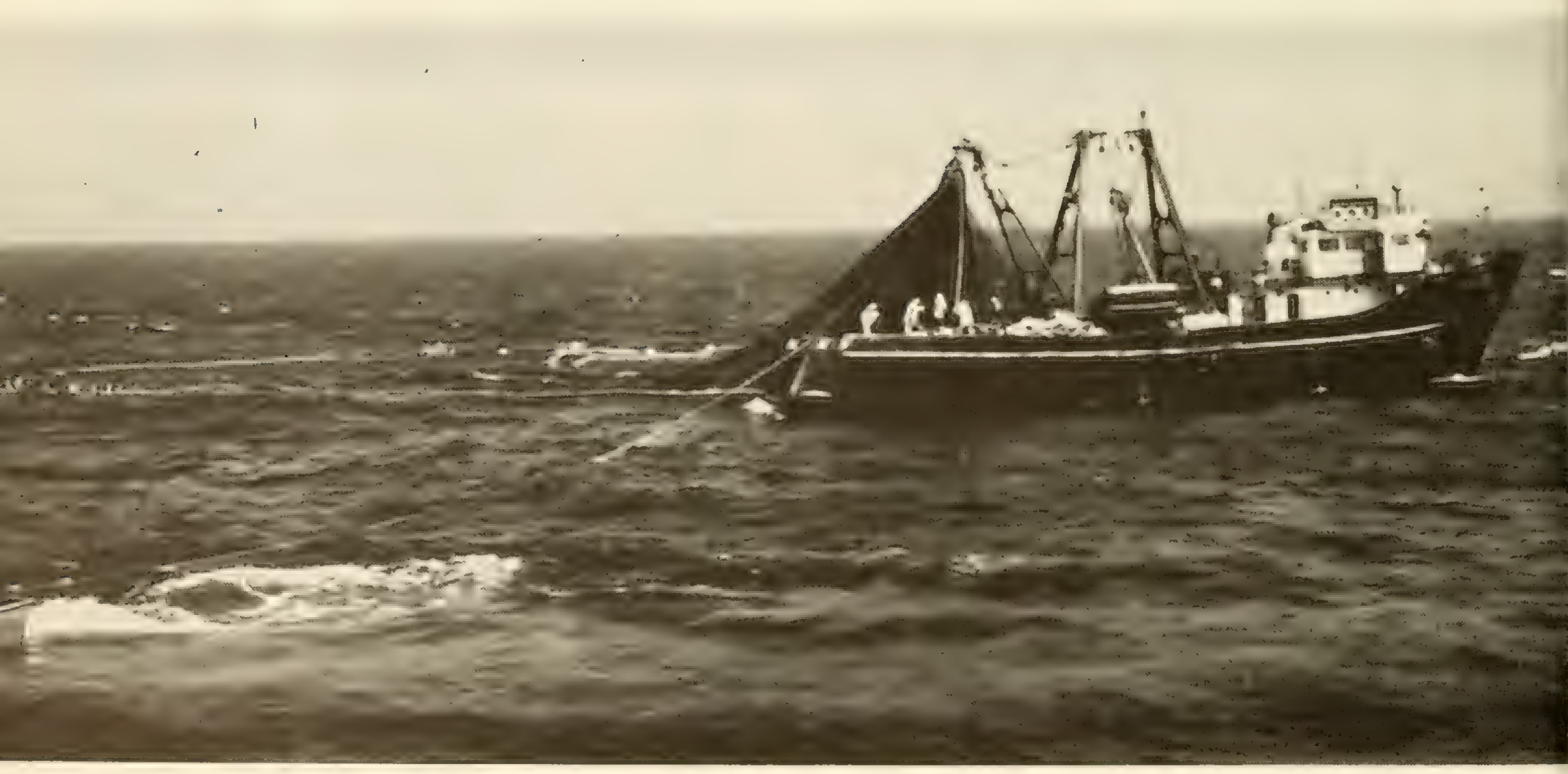
The operational success of simultaneous deployment of biological, chemical, meteorological, and physical studies in MAM 77 was the culmination of experience and learning obtained in the five earlier field programs: MESCAL I and II off Baja California, CUE-I and II off Oregon, and JOINT-I off the coast of Northwest Africa in 1974. These earlier programs paved the way for JOINT-II, because scientists in the CUEA program learned what scales of resolution are necessary to document the physical/biological coupling and how the ships and equipment should be deployed to obtain the needed resolution.

The absence of any major analysis failures (or even delays) in MAM 77 was remarkable considering the harsh environment of the south coast of Peru. The aircraft and meteorological operations faced particularly tough desert conditions, but succeeded in carrying out their observations as scheduled. The assistance of the Government of Peru was a key factor when the WECOMA and the MELVILLE needed emergency drydocking. The Instituto del Mar del Peru arranged for the use of the Peruvian Navy drydock during a scheduled port call. This vital assistance kept the vessel operations on schedule.

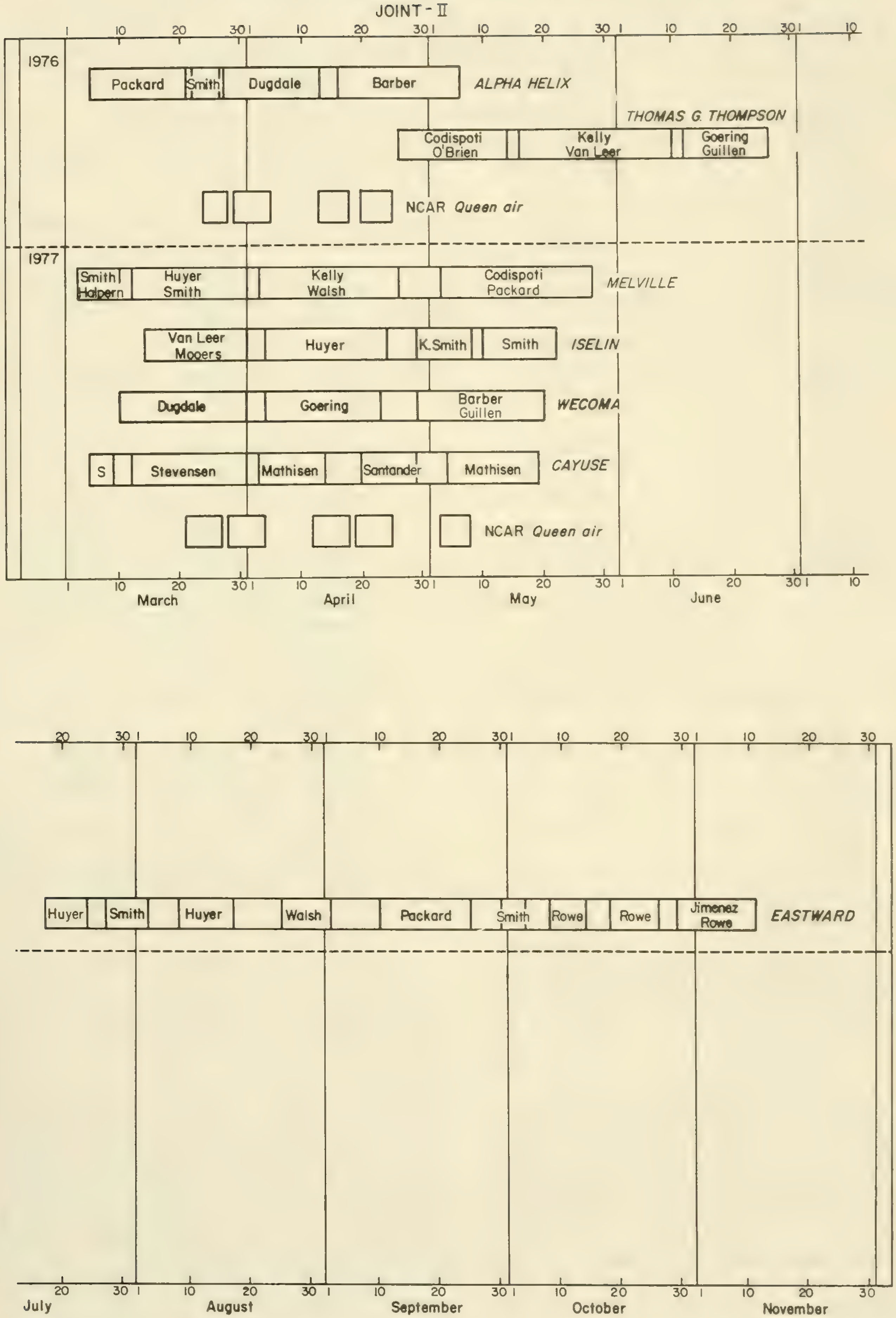
The prevailing oceanographic conditions in the intensive period of MAM 76 were distinctly different from those prevailing in MAM 77. It is too early to provide a causal explanation of the differences between the 2 years, but the characteristics can be stated. During spring 1976, the ocean was distinctly warmer than the long-term average, and the entire coastal region from 5° S to 17° S was dominated by a single species of phytoplankton, the dinoflagellate, *Gymnodinium splendens*. The biomass of the dinoflagellate was very high, but the absolute primary production was lower than that occurring in the same area at the same time of year in 1966 and 1969 (fig. 44). A very large increase in the jellyfish population accompanied the dinoflagellate bloom all along the Peru coast. The jellyfish fouled fishing equipment and oceanographic gear and, as preda-



Buoy deployment, JOINT-II, 1976–77, showing primary instrument locations.



Typical Peruvian fishing (bolichera) operations, pursing net on anchovy.



Ship deployment and chief scientists, JOINT-II, 1976–77.

Table 15.—U.S. institutions, investigators, and projects in CUEA

Institutions	Investigators	Projects
University of Alaska	J. Goering	Consumption and Regeneration of Silicic Acid in Upwelling Systems
Bigelow Laboratory for Ocean Sciences	R. Dugdale and J. MacIsaac	Kinetics of Nutrient Uptake
	T. Packard	Enzymatic Determination of Biological Transformation
Brookhaven National Laboratories	J. Walsh	Systems Model of Upwelling Ecosystems
	T. Whitledge	Nutrient Regeneration and Excretion
University of Delaware	C. Mooers	Physical Dynamics of the Frontal Zone
Duke University	R. Barber	Primary Production, Chelation, and Toxicity Program Management
	S. Huntsman	Primary Production, Chelation, and Toxicity.
Florida State University	Y. Hsueh	Diagnostic Modeling Studies in JOINT–II
	J. O'Brien	Simulation of Time-Dependent Coastal Upwelling Circulation
	D. Stuart	Meteorological Support and Investigations for the JOINT–II Expedition
Inter-American Tropical Tuna Commission	M. Stevenson	Plume and Frontal Structures in a Coastal Upwelling Zone by Lagrangian Measurements
University of Miami	J. Van Leer	Physical Dynamics of the Frontal Zone
Oregon State University	J. Allen	Theoretical Studies and the Dynamical Interpretation of Flow Field Observations
	A. Huyer	Mesoscale Hydrography during JOINT–II
	R. Smith	Mesoscale Circulation in Coastal Upwelling Systems
Pacific Marine Environmental Lab	D. Halpern	Near-Surface Circulation in a Coastal Upwelling Environment
San Francisco State University	J. Kelley	Nutrient and Phytoplankton Fields
		Interactive Real-Time Information System for Coastal Upwelling Studies
Scripps Institution of Oceanography	M. Blackburn	Nekton Distribution and the Environmental Factors Causing this Distribution in the Upwelling Region
	K. Smith	Carbon, Nitrogen, and Phosphorus Cycles on the Sea Floor of an Upwelling Region
University of Washington	L. Codispoti	Mesoscale Hydrography during JOINT–II
	R. Thorne and O. Mathisen	Acoustic Assessment of Nekton
Woods Hole Oceanographic Institution	G. Rowe	Carbon, Nitrogen, and Phosphorus Cycles on the Sea Floor of an Upwelling Region

tors, must have modified the normal food chain dynamics. In the 15° S region, where the intensive effort of JOINT-II was located, a layer of anoxic, denitrified, and hydrogen sulfide-bearing water developed in the undercurrent (fig. 45). The association of the dinoflagellate bloom, jellyfish, and anoxia, none of which was present in MAM 77, lead the CUEA scientists to look for fundamental differences in the atmospheric and oceanographic forcing processes for the two periods, MAM 76 vs. MAM 77. Indeed, the requisite differences appear to be present in some large-scale properties, but not necessarily in the local wind fields.

MAM 77, distinctly different from MAM 76, is also quite distinct from the conditions prevailing at the JOINT-II site in 1966 and 1969. Primary production was lower, and the persistent upwelling center just south of Cabo Nazca was more strongly developed in terms of the characteristics of the low temperature, high nitrate, and very low chlorophyll (fig. 46). First analysis suggests that MAM 77 was a period of stronger than average upwelling, especially in relation to the conditions present in 1966 and 1969.

One aspect of major international consequence is that the highly unusual 1976 conditions (anoxia, dinoflagellate bloom,

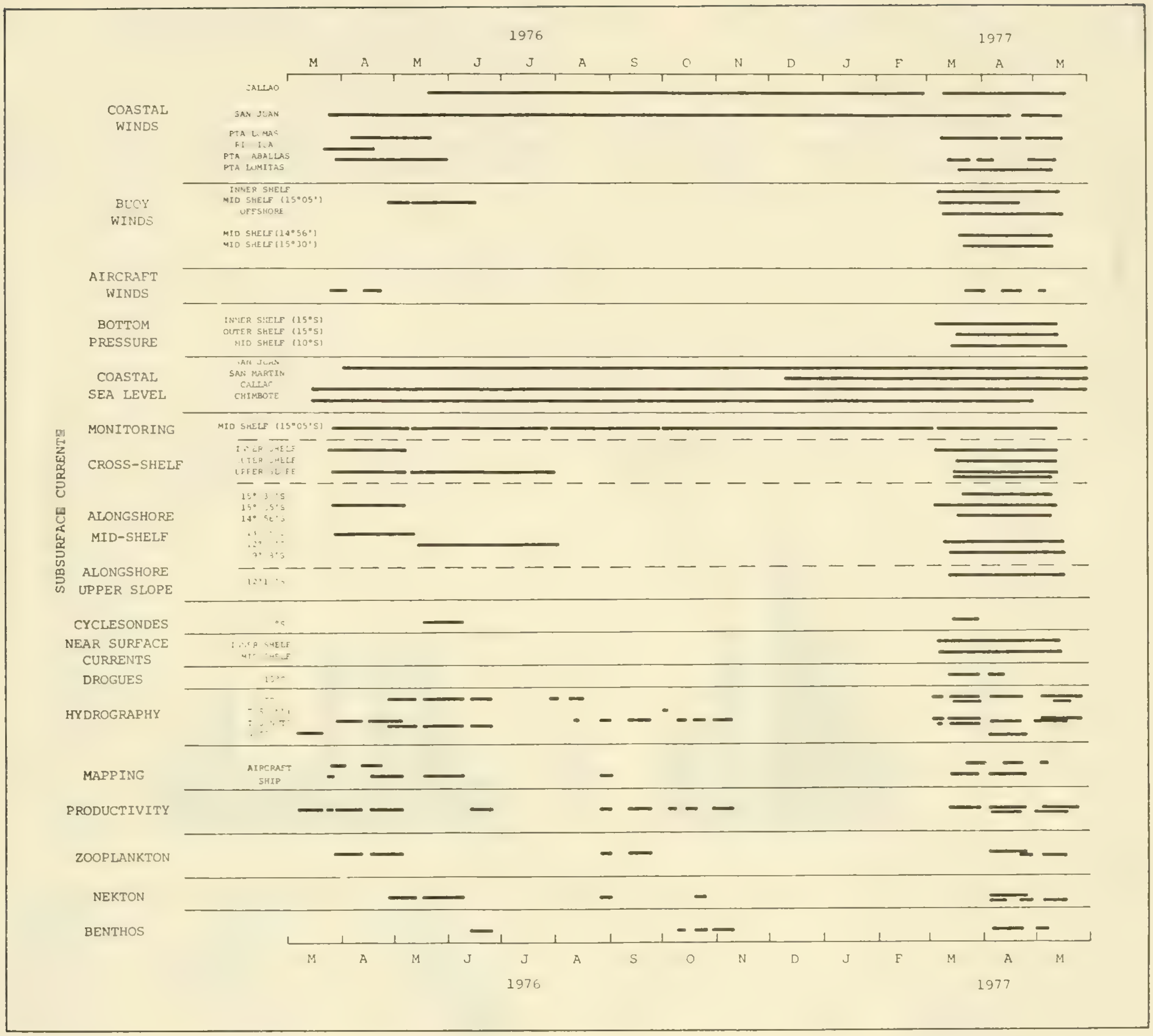


Figure 43.—Time-phase diagram of the CUEA JOINT–II observations in the Peru coastal upwelling region, 1976–1977.

and jellyfish) were accompanied by a widespread failure of anchovy reproduction. The closure of the anchovy fishery had an international economic ripple effect and imposed considerable hardship on the economy of Peru. The distinctly different conditions present in MAM 77 and the absence of any of the strong anomaly indicators (anoxia, dinoflagellates, and jellyfish) provide a basis for predicting that the reproductive failure will not be repeated this year. The oceanographic observations of JOINT-II for MAM 77 have been used by the Government of Peru to evolve their strategy for fishery management during this critical period. Thus, social application and scientific analysis of JOINT-II are proceeding simultaneously.

With completion of the JOINT-II field work in mid-1977, CUEA began data processing, analysis, interpretation, and synthesis (called SYNAPSE—Synthesis and Publication Segment), which will be the full project effort for at least the next 2 years. The plan for SYNAPSE involves individual component data processing and analysis, small group interactions, program-wide meetings and workshops for data synthesis, national and international forums for presentation to the scientific community, and publication of data and synthesized results.

CUEA Data

CUEA data received during the period of this report are available from NODC as follows:

NODC Accession No.: 78-0403
Organization: Oregon State University
Investigators: R. L. Smith (OSU), A. Huyer (OSU)
Grant No.: OCE74–22290, ID071–04211
Project: WISP/UP–75
Data: 117 CTDs taken aboard 8 cruises of the RV Yaquina off the Oregon coast from January 27, 1975, to July 29, 1975. Data submitted on NODC-compatible tape.

NODC Accession No.: 78–0403
Organization: Oregon State University

Investigators: A. Huyer (OSU), R. L. Smith (OSU)
Grant Nos.: OCE74–22290, ID071–04211
Project: WISP/UP–75
Data: Buoy-moored current meter observations: 24 files of depth, velocity, U, and V components from January 28, 1975, to September 12, 1975; temperatures and salinities taken aboard RV YAQUINA, August 1 to September 12, 1975. Data submitted on NODC-compatible magnetic tape.

NODC Accession No.: 77–0121
Organization: Oregon State University
Investigator: H. Pak (OSU)
Grant No.: ID071–04211
Project: CUEA
Data: 83 optical measurements taken aboard RV YAQUINA Cruise Y–7408B in August 1974 off the Oregon coast. Data were submitted on punched cards.

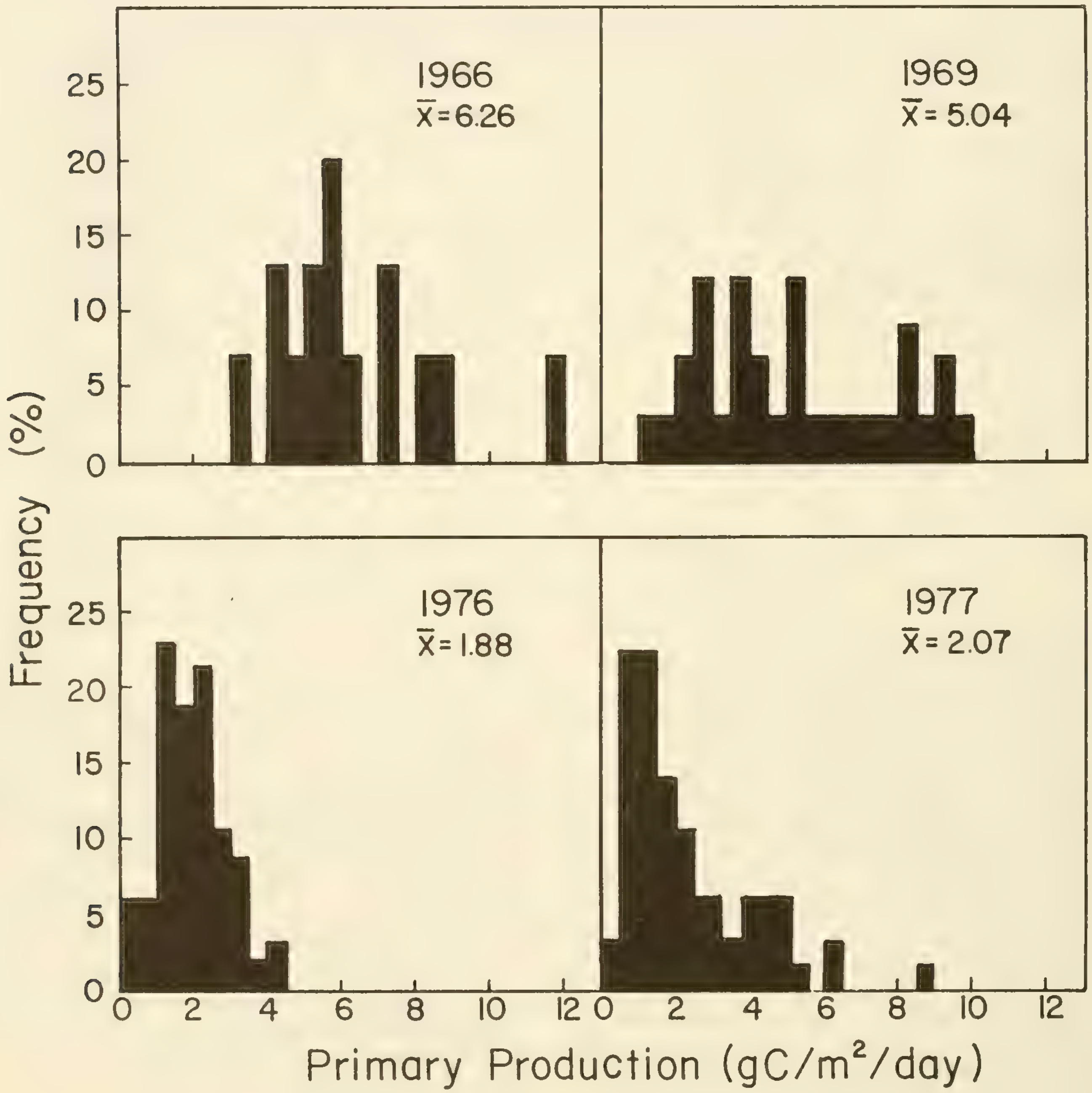


Figure 44.—A comparison of primary production frequency distributions in the 15°S latitude region off the Peru coast. The data are all from the Cabo Nazca area where JOINT II was conducted in March and April 1975 and 1977. RV PISCO sailed in 1969 and ANTON BRUUN in 1966. The dramatically lower primary production in 1976 and 1977 relative to 1966 and 1969 is clear.

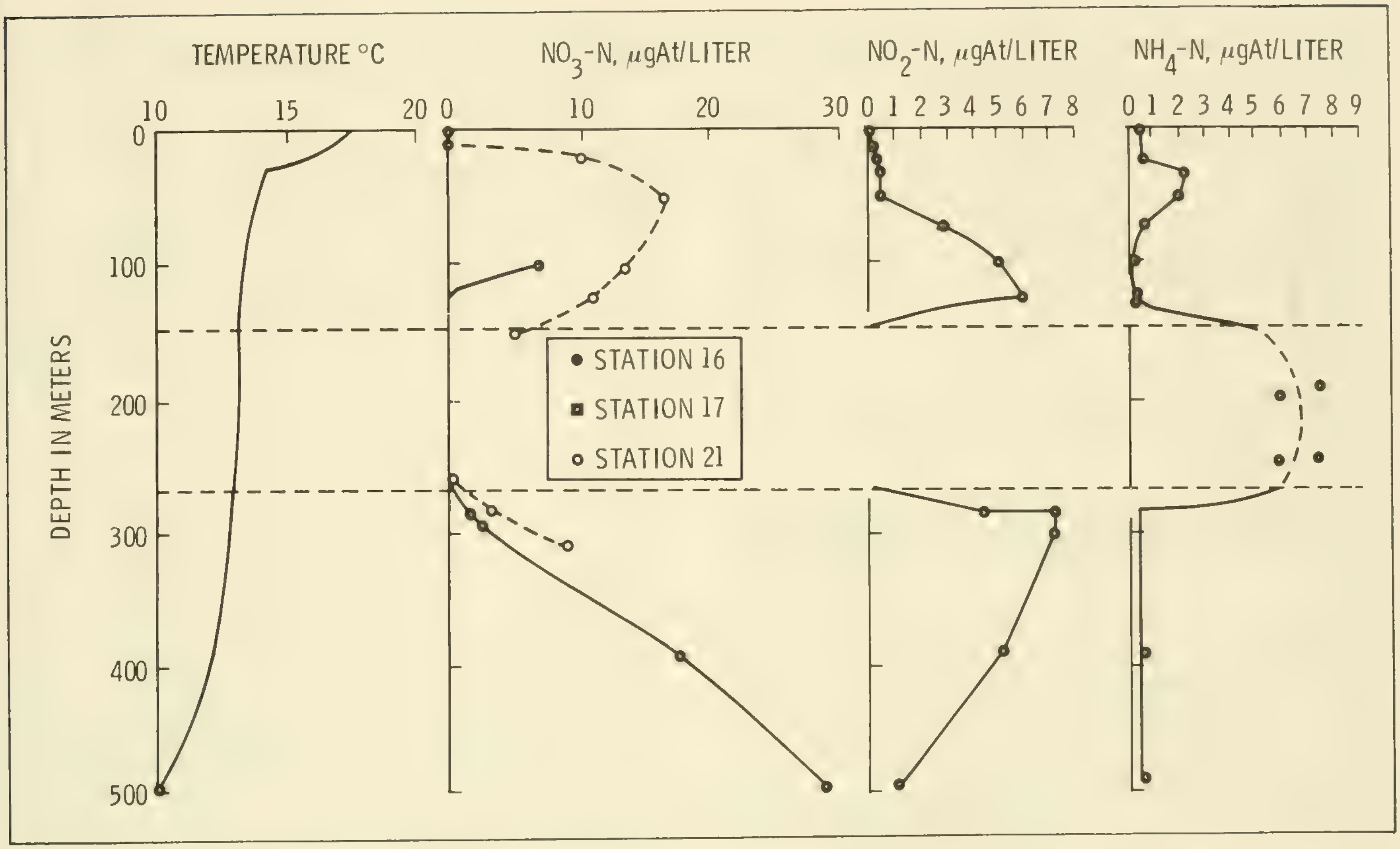


Figure 45.—Profiles of temperature and nutrients at location C–5 (intensive site) off Peru, 15°S, April 1–3, 1976.

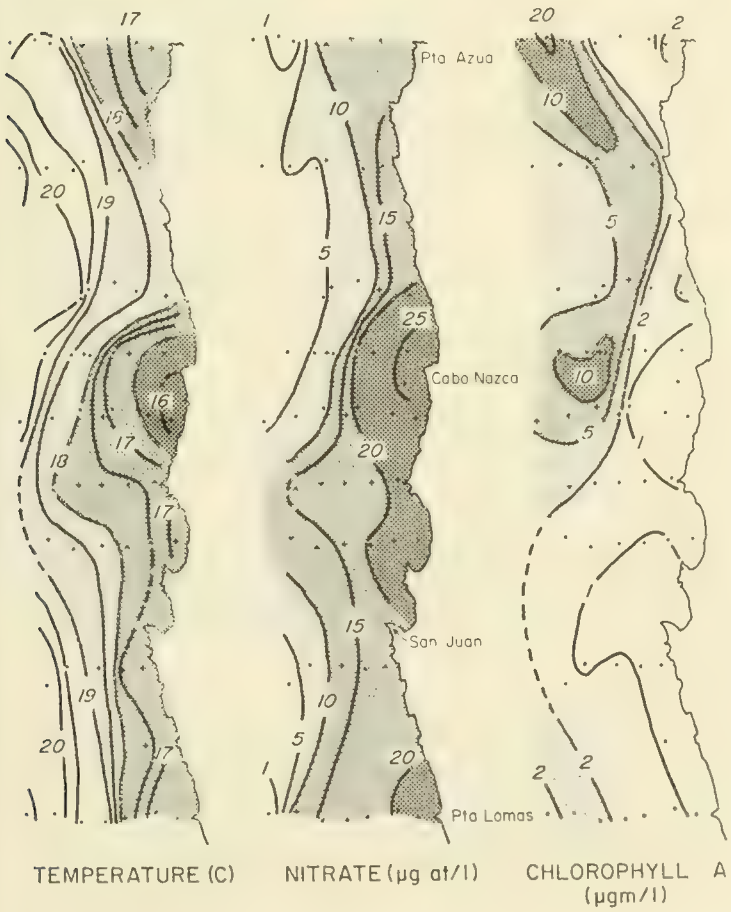


Figure 46.—Distribution of temperature, nitrate, and chlorophyll around the Cabo Nazca site, where the intensive JOINT–II studies were located. The alongshore and offshore expansion of the traditional Cabo Nazca upwelling center emphasizes the strength of the upwelling in 1977 as compared with data from the same months in previous years.

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Seagrass Ecosystem Study (SES)

The Seagrass Ecosystem Study (SES) began in 1974 as a team research project to study benthic marine plant systems, particularly the dynamic processes by which seagrass ecosystems are maintained and how they contribute to the seas.

In the past 2 years, the second phase of the research (SES II) has been completed and has resulted in a great deal of new information and progress toward the stated goals of the project. This research generally addresses three main questions. What are the contributions of seagrass ecosystems to food

In situ coring of *Thallasia* reefs east of New Cay.

webs, nutrient and mineral cycling, and coastal stabilization? What processes in seagrass ecosystems are affected by environmental changes or human induced perturbations? Are there structural patterns in these ecosystems that allow them to persist in changing environments?

Research has now focused on understanding the development of these systems in terms of both local and latitudinal gradients. The central hypothesis of the project is based on the principals of ecological succession—succession of species, structures, and functions—and this unifying concept has led to considerable understanding and progress. Work has generally been confined to the *Zostera* (eelgrass) system, characteristic of north temperate regions, and the *Thalassia* (turtle grass) system, characteristic of the Tropics.

Laboratory studies and field work in Alaska and St. Croix, U.S.V.I., have shown that the development of the plant component of the seagrass community, and subsequently the animal component, is keyed to chemical and microbial processes in the sediments. This keying results in a gradient of development that can be seen across any local seagrass bed and probably also in the latitudinal distribution patterns. These results have led to the refined hypotheses that seagrass ecosystems represent mature as well as colonizing and intermediate stages of development, that the degree of development reached in any specific location depends on the interaction of environmental constraints and ecological processes, and that only under optimum conditions will a mature system develop. A corollary is that less than optimum conditions will result in a less mature seagrass system.

To test these hypotheses for the tropical *Thalassia* system, which in the American Tropics includes *Thalassia testudimum, Syringodium fili, Halodule wrightii,* and *Halophila* spp., an expedition was made aboard the RV ALPHA HELIX to the Miskito banks off the coast of Nicaragua. (See fig. 47.) The Nicaraguan shelf is the largest in the Caribbean and is renowned as a major feeding area for the seagrass-eating green turtle (*Chelonia mydas*). Previously, work on the tropical seagrasses had been in Texas and Florida, near the northern limits of the system, and in St. Croix on the eastern edge of the Caribbean. The expedition to Nicaragua sought to examine the *Thalassia* system, in what are presumably optimal conditions for the Caribbean Sea, as a basis of comparison for the continuing research at other sites.

The Miskito banks were found to contain a huge offshore seagrass meadow that extended out to depths of about 20 m, but was excluded from a nearshore zone about 1 to 2 miles wide by a belt of turbid, low-salinity water. A series of transects were used to quantitatively study the biota of the seagrasses and associated coral reef and mangrove habitats. The results indicate a gradient of detritus in the sediment that decreases with distance from the mangrove cays. As in other areas studied, the plant and animal community reflects the sediment gradient. Sea urchins are often major herbivores in seagrass beds, and on the Miskito banks the common species, *Lythechinus variegatus,* was studied to determine its association with the seagrasses. The conclusion of the studies was that in contrast to other areas, *Lythechinus* in this area could hardly be considered a herbivore, because it apparently derived most of its nutrition from bryozoans that are epiphytic on seagrass leaves. Related research examined the relationship between coral reefs and seagrass beds; this relationship is most obvious where heavily grazed seagrasses around a reef form a sand "halo." It appears that reef dwelling organisms on the Miskito banks exert an influence on the surrounding seagrasses for as much as 20 m from the reef.

Green turtles concentrate on the Miskito banks during late fall and winter. These animals are the basis of the culture and a traditional fishery of the Miskito Indians. Green turtles are primarily seagrass consumers, and hence the coastal peoples of the region are closely tied to the productivity of the seagrass beds. The results of the studies on the digestive physiology of the turtles showed that these animals are indeed true herbivores capable of symbiotic cellulose digestion; assimilation of total carbohydrates and cellulose is estimated to exceed 90 percent. The process is not unlike ruminant mammals, but this is the first established example of symbiotic cellulose digestion in a reptile. Analysis of the carbon isotope ratio of turtle flesh confirmed that the animal could not be isotopically distinguished from the seagrasses it eats. In addition, T. Fenchel (cooperative participant from Denmark) discovered a new cilliate species (possibly genus) in the microbial fauna of the turtle gut.

In SES III (1978–80), the scientific approach developed in the previous studies will be expanded and intensified. A range of seagrass ecosystems will be examined over latitudinal and local environmental gradients. Two major sites have been selected for intensive study—a tropical one on St. Croix, U.S.V.I., and a north temperate one on the Alaska Peninsula. (See fig. 48.) There are also several ancillary sites on the Pacific and Atlantic coasts of America that will be used to interpret latitudinal patterns. In addition, two other major expeditions are being planned as international cooperative studies. First, in 1979 will be a cooperative expedition with Australian, Danish, and Japanese scientists to the Torres Strait region of Australia; this area is considered the biogeographical center of seagrasses. The second expedition, still under consideration, would be in cooperation with Mexican scientists to study the seagrass beds of the Gulf of California; this area represents the southern extent of the *Zostera* system on the Pacific coast of America. Both expeditions are viewed as tests of the general hypothesis from a latitudinal perspective. Table 16 identifies participants in SES.

International cooperation and interest in seagrasses has increased greatly in the past few years, and now at least 20 nations have active groups of seagrass researchers. International collaboration is generally maintained through the International Seagrass Committee, whose members include: Tom Fenchel, Denmark; J. M. Peres, France; Akhiko Hattori, Japan; D. Den Hartog, the Netherlands; and Peter McRoy and Patrick L. Parker, United States. A meeting of the Committee will be held in conjunction with a seagrass symposium as a part of the Second International Congress of Ecology in September 1978.

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Figure 47.—Research site of the SES expedition (RV ALPHA HELIX) to the Miskito Banks, western Caribbean Sea.

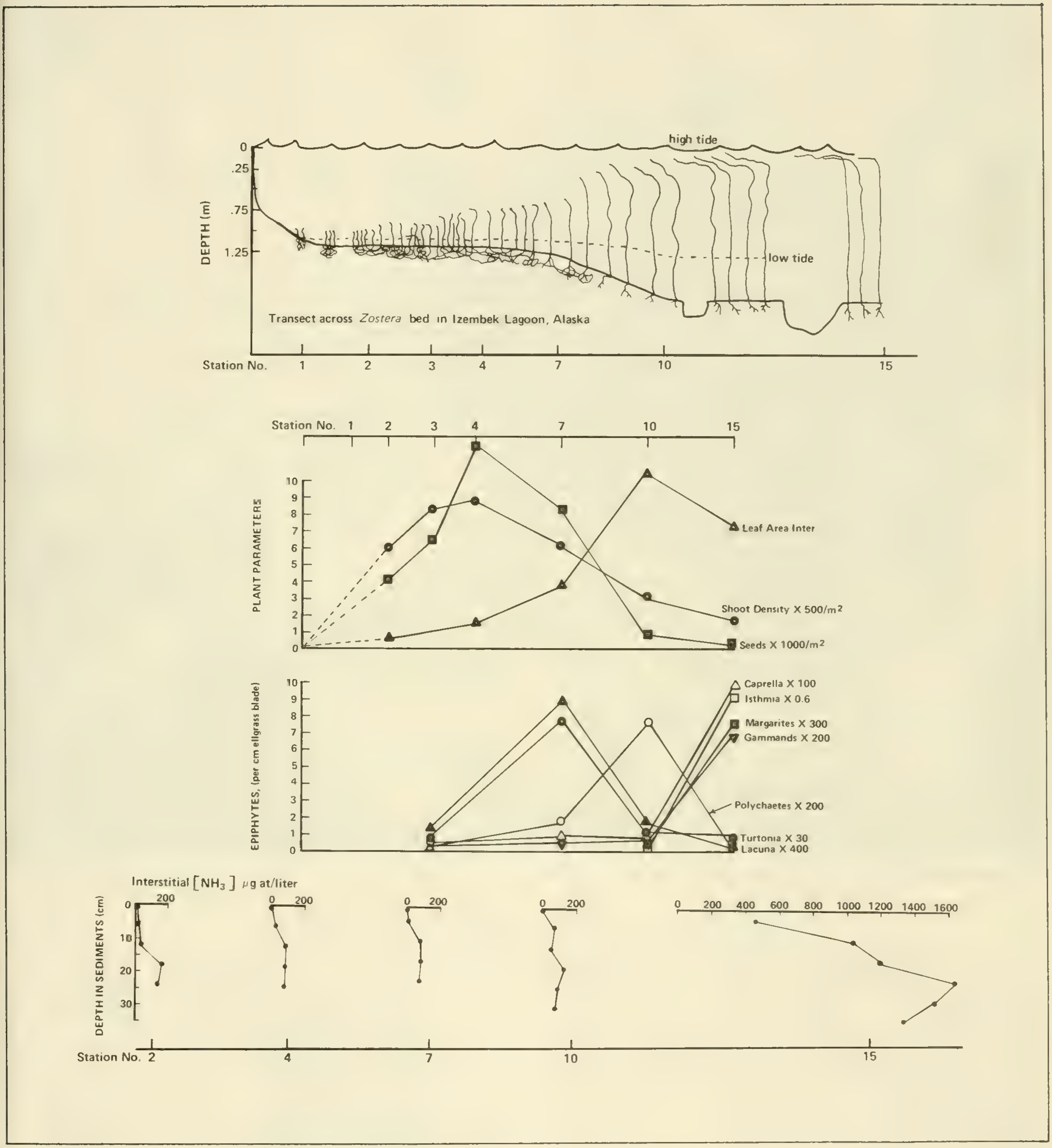


Figure 48.—Patterns of community parameters measured across a *Zostera* meadow in Alaska.

Working up collection of reef fish in laboratory of RV ALPHA HELIX.

Table 16.—U.S. institutions, investigators, and projects in SES

Institutions	Investigators	Projects
University of Alaska	P. McRoy	Process Succession in Seagrass Ecosystems
Fairleigh Dickinson University	J. Ogden	Caribbean Seagrass Food Web Study
Florida State University	R. Iverson	Primary Production Studies in Seagrass Ecosystems
University of Hawaii	K. Bridges	Systematic Ecology
		Project Management
Michigan State University	M. Klug and R. Wetzel	Decomposition of Dissolved and Particulate Organic Detritus in Seagrass Ecosystems
Seattle Pacific College	R. Phillips	Interrelationships of Phenology and Transplanting in the Analysis of Seagrass Stability
University of Texas	P. Parker and R. Scalan	Stable Carbon Isotope Ratios of Food Webs and Biogeochemical Cycles in Seagrass Ecosystems
	C. McMillan	Environmental Tolerances of Seagrasses
University of Virginia	J. Zieman	Caribbean Seagrass Food Web Study

Appendix A—ROSCOP Summaries

In the following ROSCOP (Report of Observations/ Samples Collected by Oceanographic Programs) summaries,[1] all institutions or activities are U.S. participants in IDOE, and all projects are part of the Declared National Program (DNP) for Marine Data Exchange. This appendix includes all IDOE-related ROSCOPs received by NOAA's Environmental Data and Information Service from April 1977 to April 1978. The reported ROSCOPs bring the IDOE 1970 to 1978 total to 528. Information is presented in the following order:

Line 1: Name of vessel or platform used to collect the data, name of institution operating the vessel or platform[2], ship cruise number.

Line 2: Inclusive dates of the cruise or platform deployment; general ocean area of cruise; and 10° Marsden square(s) where observations and samples were collected, as shown by charts following appendices.

Line 3: NODC Reference Number. (Reference to this number when requesting ROSCOPs facilitates retrieval of the information.)

Line 4: Name of principal investigator or chief scientist on the cruise, his affiliate institution[3], and the identifying number of the NSF grant that supports the principal investigator.

Line 5: Name of the IDOE project for which the cruise data and collections were made.

[1] See Introduction.
[2] Certain cooperative data collection efforts were performed on vessels other than those of the grant holder's parent institution.
[3] Certain inventory forms were submitted by institutions other than those of the grant holders.

A listing of parameters by discipline and the number of stations, observations, samples, or miles of record follow line 5. Where continuous sampling or observing has been made, the number of miles is used rather than discrete values.

LIST OF ABBREVIATIONS

Institution of IDOE Grant Holder

AOML	Atlantic Oceanographic and Meteorological Laboratories, NOAA
DUML	Duke University Marine Laboratory
FSU	Florida State University
IATTC	Inter American Tropical Tuna Commission
LDGO	Lamont-Doherty Geological Observatory
MIT	Massachusetts Institute of Technology
MLML	Moss Landing Marine Laboratory
NMFS	National Marine Fisheries Service, NOAA
NOAA	National Oceanic and Atmospheric Administration
OSU	Oregon State University
PEG/NMFS	Pacific Environmental Group, NMFS, NOAA
PMEL	Pacific Marine Environmental Laboratory, NOAA
RSMAS	Rosensteil School of Marine and Atmospheric Sciences, University of Miami
SIO	Scripps Institution of Oceanography
TAMU	Texas A&M University
URI	University of Rhode Island
U Alaska	University of Alaska
U Del.	University of Delaware
U Wash.	University of Washington
WHOI	Woods Hole Oceanographic Institution

Organizations providing support:

AEC	Atomic Energy Commission
EPA	Environmental Protection Agency
NSF–IDOE	National Science Foundation—International Decade of Ocean Exploration program
ONR	Office of Naval Research

Environmental Quality Program

Geochemical Ocean Sections Study (GEOSECS)

1. RV THOMAS G. THOMPSON (U Wash.) Cruise INDOPAC Leg 1
2. March 23 to April 30, 1976, midlatitude North Pacific
3. NODC Reference No. R391869
4. J. Edmond (MIT), Grant:NSF/OCE71–04197
5. **Program:** INDOPAC/GEOSECS

Physical/Chemical Oceanography: Trace elements–36, lead isotopes–13, barium-18, methane–1, surface net tows–19

1. RV THOMAS G. THOMPSON (U Wash.) Cruise INDOPAC Legs 2, 3
2. May 5 to June 19, 1976, equatorial western Pacific
3. NODC Reference No. R391227
4. J. I. Reid (SIO), Grant:NSF/OCE71–04197
5. **Program:** INDOPAC/GEOSECS

Physical/Chemical Oceanography: STDs–56; ocean stations–53; oxygen, phosphates, nitrates, nitrites, silicates–53 each; bottom measurements–3

1. RV WECOMA (OSU) Cruise WELOC 77 Leg 1
2. January 10 to February 2, 1977
3. NODC Reference No. R391829
4. L. I. Gordon (OSU), Grant: NSF/OCE76-00592
5. **Program:** GEOSECS

Physical/Chemical Oceanography: 221 surface temperatures, salinities, oxygen, phosphates, nitrates, nitrites, silicates, alkalinity, pH, and dissolved gasses

Environmental Forecasting Program

Mid-Ocean Dynamics Experiment (MODE) and POLYMODE

1. RV ENDEAVOR (URI) Cruise EN–007
2. April 1 to 23, 1977, western Atlantic
3. NODC Reference No. R392091
4. T. Rossby (URI), B. Taft (U Wash.), Grant: NSF/OCE76-11726
5. **Program:** LDE/Southern Synoptic Experiment

Dynamics: SOFAR floats–5

Physical/Chemical Oceanography: CTDs–60, XBTs–87, oxygen, phosphates, nitrates, nitrites, and silicates–60 each, tritium–55, nephelometer-continuous

1. RV ENDEAVOR (URI) Cruise EN–008
2. May 1 to 19, 1977, western and tropical-western Atlantic
3. NODC Reference No. R392092
4. D. R. Watts (URI), Grant:NSF/OCE76–11726
5. **Program:** LDE/Southern Synoptic Experiment

Dynamics: Inverted Echo Sounders (IES)–4

Physical/Chemical Oceanography: CTDs–31, XBTs–262, shear profiles (u, v, T, C, P)–111, ocean station–1

1. RV ENDEAVOR (URI) Cruise EN–012
2. September 6 to 22, 1977, Gulf Stream
3. NODC Reference No. R392333
4. D. R. Watts (URI), Grants:NSF/OCE77–08595, OCE77–08993
5. **Program:** Gulf Stream Rings

Dynamics: Inverted Echo Sounders (IES)–4

Physical/Chemical Oceanography: STDs–18, XBTs–321

1. RV ENDEAVOR (URI) Cruise EN–016
2. December 5 to 22, 1977, western Atlantic
3. NODC Reference No. R392378
4. W. Metcalf (WHOI), Grant:NSF/OCE77–01026
5. **Program:** POLYMODE/Core Program

Physical/Chemical Oceanography: XBTs–161

1. RV KNORR (WHOI) Cruise 66 Leg 2
2. May 26 to June 24, 1977, western and central North Atlantic
3. NODC Reference No. R392243
4. G. Tupper (WHOI), Grants:NSF/OCE75–03962, OCE76–24232
5. **Program:** POLYMODE Moorings

Geology/Geophysics: Bathymetry 1,000 nmi

Dynamics: 59 current meters, 10 months of observations

Physical/Chemical Oceanography: CTDs–48, XBTs–263, vertical current meters–2

1. RV KNORR (WHOI) Cruise 66 Leg 3
2. June 28 to July 13, 1977, western North Atlantic
3. NODC Reference No. R392244
4. K. Bradley (WHOI), Grant:NSF/OCE75–03962
5. Program: POLYMODE Moorings

Geology/Geophysics: Bathymetry 350 nmi

Dynamics: 31 current meters, 10 months of observations, drifters–4, pressure/temperature recorders–17

Physical/Chemical Oceanography: CTDs–19, XBTs–263, oxygen, nitrates, silicates, chlorinity–2,191 each

1. RV KNORR (WHOI) Cruise 71
2. October 21 to November 17, 1977, western North Atlantic
3. NODC Reference No. R392381
4. P. Richardson (WHOI), Grant:NSF/OCE75–08765
5. **Program:** Gulf Stream Rings

Dynamics: Drifters–3

Physical/Chemical Oceanography: STDs–33, XBTs–411, trace elements–33, isotopes–10, vertical oxygen profiles–13

Biology: Phytoplankton tows–23, zooplankton tows–23

1. RV RESEARCHER (NOAA) Cruise RP–1–RE–77
2. March 1 to 21, 1977, western tropical Atlantic
3. NODC Reference No. R392148
4. A. Leetmaa (AOML), Grant:NSF/AG385
5. **Program:** LDE/Southern Synoptic Experiment

Dynamics: Sea and swell–484

Physical/Chemical Oceanography: CTDs–18, XBTs–445, drogues–5

North Pacific Experiment (NORPAX)

1. RV THOMAS G. THOMPSON (U Wash.) Cruise INDOPAC Leg 1
2. March 23 to April 30, 1976, mid-latitude North Pacific
3. NODC Reference No. R391869
4. K. E. Kenyon (SIO) Grant:NSF/OCE74–18316
5. **Program:** NORPAX-Anomaly Dynamics Study

Physical/Chemical Oceanography: STDs–98; ocean stations–98; XBTs–570; oxygen–98; phosphates, nitrates, nitrites, silicates–49 each

1. RV THOMAS G. THOMPSON (U Wash.) Cruise INDOPAC, Legs 2, 3
2. May 5 to June 19, 1976, equatorial western Pacific
3. NODC Reference No. R391227
4. D. L. Cutchin (NSF–IDOE), C. A. Collins (NSF–IDOE), Grant:NSF/OCE76–01150
5. **Program:** INDOPAC/NORPAX

Physical/Chemical Oceanography: XBTs–340

1. RV THOMAS G. THOMPSON (U Wash.) Cruise INDOPAC Leg 7
2. August 14 to 29, 1976, equatorial western Pacific
3. NODC Reference No. R391873
4. W. Patzert (SIO), Grant:NSF/OCE76–17471
5. **Program:** NORPAX-Equatorial Currents

Dynamics: Current meters–3
Physical/Chemical Oceanography: STDs–22, ocean stations–22

1. RV THOMAS G. THOMPSON (U Wash.) Cruise ADS–3
2. May 16 to June 14, 1977, western North Pacific
3. NODC Reference No. R392213
4. A. D. Kirwan (TAMU), Grant:NSF/OCE76–10177
5. **Program:** NORPAX-Anomaly Dynamics Study

Physical/Chemical Oceanography: STDs–78, ocean stations–78, XBTs–137, surface salinity–105

NORPAX-XBTs—Pacific Ships of Opportunity

1. CALIFORNIAN, 3 tracks between Seattle and Hawaii, 2 tracks between San Francisco and Hawaii
2. April 2 to August 27, 1977, eastern North Pacific
4. D. McLain (PEG/NMFS), Grant:NSF/OCE75–23357
5. **Program:** IDOE/EF–NORPAX/Pacific Ships of Opportunity

Number of crossings–5, XBTs–106

1. CHEVRON HAWAII, tracks between San Francisco and Hawaii
2. April 14 to June 9, 1977, eastern North Pacific
4. D. McLain (PEG/NMFS), Grant:NSF/OCE75–23357
5. **Program:** IDOE/EF–NORPAX/Pacific Ships of Opportunity

Number of crossings–4, XBTs–113

1. CHEVRON MISSISSIPPI, tracks between San Francisco and Hawaii
2. July 4 to August 4, 1977, eastern North Pacific
4. D. McLain (PEG/NMFS), Grant:NSF/OCE75–23357
5. **Program:** IDOE/EF–NORPAX/Pacific Ships of Opportunity

Number of crossings–2, XBTs–67

1. HAWAIIAN QUEEN, 9 tracks between San Francisco and Hawaii, 1 track from Seattle to Hawaii
2. April 23 to July 26, 1977, eastern North Pacific
4. D. McLain (PEG/NMFS), Grant:NSF/OCE75–23357
5. **Program:** IDOE/EF–NORPAX/Pacific Ships of Opportunity

Number of crossings–10, XBTs–300

International Southern Ocean Studies (ISOS)

1. RV MELVILLE (SIO) Cruise F DRAKE 77
2. January 10 to February 15, 1977, Drake Passage
3. NODC Reference No. R391785
4. W. D. Nowlin, Jr. (TAMU), R. D. Pillsbury (OSU), Grants:NSF/OCE74–04941 A02, NSF/OCE76–80066
5. **Program:** ISOS/F DRAKE 77

Dynamics: Current meters–6 for 300 days, tide observations for 1 year
Physical/Chemical Oceanography: CTDs–48, ocean stations–48, XBTs–109, discrete temperatures and salinities–157, oxygen–48
Geology/Geophysics: Bathymetry–4,000 nmi, magnetism–2,000 nmi

1. AGS YELCHO (Chile) Cruise F DRAKE 76 Legs 1, 2
2. February 27 to April 8, 1976, Drake Passage
3. NODC Reference No. R070001
4. H. A. Sievers (Chile Hydrographic Office), S. L. Patterson (TAMU), Grant:NSF/OCE74–04941 A02
5. **Program:** ISOS/F DRAKE 76

Physical/Chemical Oceanography: XBTs–571, discrete temperatures and salinities–569

1. AGS YELCHO (Chile) Cruise F DRAKE 77
2. November 29 to December 22, 1977, Drake Passage
3. NODC Reference No. R392457
4. W. D. Nowlin, Jr. (TAMU), R. D. Pillsbury (OSU), Grants:NSF/OCE74–04941 A02, NSF/OCE76–80066
5. **Program:** ISOS/F DRAKE 77

Dynamics: Current meters–21 for 320 days, pressure gauges–2, ocean stations–2, XBTs–79

Climate: Long-Range Investigation, Mapping, and Prediction (CLIMAP) Study

1. RV WECOMA (OSU) Cruise WELOC 77 Leg 7
2. June 29 to July 3, 1977, Pacific Ocean off Oregon coast
3. NODC Reference No. R392136
4. H. J. Schrader (OSU) Grant:NSF/OCE75–22133
5. **Program:** CLIMAP

Geology/Geophysics: Cores–2, seismic reflections–25, paleontology–1, geochronology–1

1. RV WECOMA (OSU) Cruise W7710A
2. October 6 to 15, 1977, eastern North Pacific off Oregon coast
3. NODC Reference No. R392326
4. H. J. Schrader (OSU), Grant:NSF/OCE75–22133
5. **Program:** CLIMAP/Coring

Geology/Geophysics: Cores–31

Indian Ocean Experiment (INDEX)

1. RV ATLANTIS–II (WHOI) Cruise A–II 93 Leg 15

2. December 12, 1976 to January 10, 1977, equatorial Indian Ocean
3. NODC Reference No. R392459
4. J. Luyten (WHOI), Grant:NSF/OCE75–03962
5. **Program:** INDEX

Dynamics: Current meters–5 for 210 days, drifters–7, profiling current meters–28

Physical/Chemical Oceanography: STDs–28

Geology/Geophysics: Bathymetry–6,000 nmi

Seabed Assessment Program

Plate Tectonics and Metallogenesis Studies

1. RV KNORR (WHOI) Cruise K–64 Leg 2
2. February 8 to March 1, 1977, eastern equatorial Pacific
3. NODC Reference No. R392460
4. R. von Herzen (WHOI), R. Ballard (WHOI), Grant:NSF/OCE76–00389
5. **Program:** Galapagos Spreading Center

Physical/Chemical Oceanography: STDs–2, seafloor water samples–250

Geology/Geophysics: Cores–6, photos–12, geothermy–100

1. RV KNORR (WHOI) Cruise K–64 Leg 3
2. March 5 to 24, 1977, eastern equatorial Pacific
3. NODC Reference No. R392241
4. J. Corliss (OSU), R. Ballard (WHOI), Grants:NSF/OCE75–23352, NSF/OCE76–00389
5. **Program:** Galapagos Spreading Center

Geology/Geophysics: Cores–10, drilling–6, bottom photo-6,000 frames, heat flow–160, bottom movies (ALVIN)–15 to 20 min

1. RV THOMAS WASHINGTON (SIO) Cruise INDOPAC Leg 4
2. June 22 to July 4, 1976, equatorial western North Pacific
3. NODC Reference No. R391870
4. J. W. Hawkins (SIO), Grant:NSF/OCE75–19148
5. **Program** Metallogenesis

Physical/Chemical Oceanography: XBTs–15

Geology/Geophysics: Dredge–9, core–1, geothermy–1, bathymetry–2,494 nmi, seismic reflection–2,299 nmi, gravimetry–2,494 nmi, magnetism 2,351 nmi

1. RV WECOMA (OSU) Cruise WELOC–77 Leg 2
2. May 18 to June 28, 1977, eastern equatorial South Pacific
3. NODC Reference No. R392135
4. E. Suess (OSU), L. D. Kulm (OSU), Grant: NSF/OCE76–05903
5. **Program:** Continental Margin off Western South America

Physical/Chemical Oceanography: Optics–23

Geology/Geophysics: Dredge–13, cores–67, bathymetry–3,800 nmi, seismic reflection–3,800 nmi

Studies in East Asia Tectonics and Resources (SEATAR)

1. RV THOMAS WASHINGTON (SIO) Cruise INDOPAC Leg 5
2. July 8 to 26, 1976, Philippine Sea
3. NODC Reference No. R391871
4. G. G. Shor (SIO), Grant:NSF/OCE75–19387
5. **Program:** INDOPAC Expedition

Physical/Chemical Oceanography: XBTs–33, continuous surface temperature–1,000 nmi

Biology: Zooplankton–1, neuston–19, nekton–1, pelagic fish–1

Geology/Geophysics: Cores–5, bathymetry–3,010 nmi, seismic reflection–2,600 nmi, seismic refraction–32 stations, gravimetry–3,083 nmi, magnetism–2,233 nmi, sonobuoys–12

1. RV THOMAS WASHINGTON (SIO) Cruise INDOPAC Leg 8
2. September 2 to 29, 1976, Arafura Sea, Ceram Sea, Timor Sea, Philippine Sea
3. NODC Reference No. R391874
4. G. G. Shor (SIO), Grant:NSF/OCE75–19387
5. **Program:** INDOPAC Expedition

Physical/Chemical Oceanography: STDs–13, ocean stations–14, XBTs–25

Biology: Zooplankton–1, neuston–24, nekton–1

Geology/Geophysics: Cores–11, bathymetry–4,588 nmi, seismic reflection–3,770 nmi, seismic refraction–27 stations, gravimetry–4,639 nmi, magnetism–3,900 nmi

Manganese Nodule Program (MANOP)

1. RV MELVILLE (SIO) Cruise PLEIADES Leg 3
2. July 15 to August 15, 1977, equatorial eastern North Pacific
3. NODC Reference No. R391875
4. W. M. Berger (SIO), Grant: NSF/OCE77–01157
5. **Program:** MANOP

Physical/Chemical Oceanography: Ocean stations–20, continuous temperatures–2,300 nmi

Geology/Geophysics: Cores–58, seafloor temperature–15, bathymetry–5,661 nmi, seismic reflection–2,955 nmi, magnetism–5,214 nmi

Biology: Iron isotopes in zooplankton–6, plankton pump–5,000 nmi

1. RV MELVILLE (SIO) Cruise PLEIADES Leg 4 (MN7601)
2. August 20 to September 23, 1976, equatorial eastern North Pacific
3. NODC Reference No. R391876
4. F. N. Spiess (SIO), J. Greenslate (SIO), Grants: NSF/OCE76–05262, NSF/OCE75–12968
5. **Program:** MANOP

Dynamics: Current meters–2 for 10 days

Physical/Chemical Oceanography: Discrete temperatures and salinities–2; oxygen, phosphates, nitrates, nitrites, silicates, alkalinity, pH, trace elements, radioactivity–2 each

Geology/Geophysics: Dredge–1; grabs, cores, bottom photos, acoustical and engineering properties of the sea floor, radioactivity–2 each; side scan sonar, seismic reflection–230 nmi each

Living Resources Program

Coastal Upwelling Ecosystems Analysis (CUEA)

1. RV CAYUSE (OSU) Cruise CALOC–77 Leg 0
2. February 7 to March 8, 1977, eastern South Pacific off Peru
3. NODC Reference No. R392130
4. M. Stevenson (IATTC–SIO), Grant:NSF/IDO72–06422
5. **Program:** CUEA/JOINT–II MAM 77

Physical/Chemical Oceanography: STDs–9, ocean stations–9, discrete temperatures and salinities–9, nutrients-9

1. RV CAYUSE (OSU) Cruise CALOC–77 Leg 1
2. March 9 to 31, 1977, eastern South Pacific off Peru
3. NODC Reference No. R392134
4. M. Stevenson (IATTC–SIO), Grant: NSF/IDO72–06422
5. **Program:** CUEA/JOINT–II MAM 77

Dynamics: Drogues–4
Physical/Chemical Oceanography: STDs–163, discrete temperatures and salinities–85 each

1. RV CAYUSE (OSU) Cruise CALOC–77 Leg 2
2. April 3 to 13, 1977, eastern South Pacific off Peru
3. NODC Reference No. R392131
4. O. A. Mathisen (U Wash.), Grant: NSF/OCE76–00598
5. **Program:** CUEA/JOINT–II MAM 77

Dynamics: Drogues–2
Biology: Zooplankton stations–15, nekton recording–75

1. RV CAYUSE (OSU) Cruise CALOC–77 Leg 3
2. April 20 to 28, 1977, eastern North Pacific off Oregon
3. NODC Reference No. R392132
4. H. Santander (Instituto del Mar del Peru), Grant: NSF/OCE76–00598
5. **Program:** CUEA/JOINT–II MAM 77

Biology: Zooplankton–30 stations

1. RV CAYUSE (OSU) Cruise CALOC–77 Leg 4
2. May 4 to 18, 1977, eastern North Pacific off Oregon
3. NODC Reference No. R392133
4. O. A. Mathisen (U Wash.), Grant: NSF/OCE76–00598
5. **Program:** CUEA/JOINT–II MAM 77

Chemical Oceanography: Trace elements–10
Biology: Nekton–150 hours recording, zooplankton respiration–10 stations, spatial and temporal distributions–150 hours recording

1. RV CAYUSE (OSU) Cruise CALOC II–77 Leg 1
2. August 15 to September 2, 1977, eastern North Pacific
3. NODC Reference No. R392397
4. J. H. Martin (MLML), Grant: NSF/OCE75–01303
5. **Program:** CUEA/Cadmium Transport–Poleward Undercurrent

Physical/Chemical Oceanography: XBTs–21; phosphates, nitrates, nitrites, silicates, chlorinity–12 each.
Biology: Primary productivity–2, phytoplankton pigments–6, POC–30, PON–30, phytoplankton–7, zooplankton–9

1. RV CAYUSE (OSU) Cruise CALOC–II 77 Leg 2
2. September 3 to 21, 1977, eastern North Pacific
3. NODC Reference No. R392396
4. J. H. Martin (MLML), Grant: NSF/OCE75–01303
5. **Program:** CUEA/Cadmium Transport–Poleward Undercurrent

Physical/Chemical Oceanography: Ocean stations–2; XBTs–12; phosphates, nitrates, silicates, chlorinity-24 each; discrete temperatures and salinities–15.
Biology: Phytoplankton–12, zooplankton–12.

1. RV CAYUSE (OSU) Cruise C–7710A Leg 2
2. October 10 to 11, 1977, eastern North Pacific off Oregon
3. NODC Reference No. R392289
4. R. L. Smith (OSU), Grant: NSF/OCE77–07932
5. **Program:** CUEA/Poleward Undercurrent

Dynamics: Current meters–1 for 70 days

1. RV CAYUSE (OSU) Cruise C7712A
2. December 8, 1977 (1 day), eastern North Pacific off Oregon
3. NODC Reference No. R392463
4. B. Hickey (U Wash.), Grant: NSF/OCE77–07932
5. **Program:** CUEA/Poleward Undercurrent

Current meters–6

1. RV COLUMBUS ISELIN (RSMAS) Cruise CI7702 Leg 1
2. March 15 to 31, 1977, eastern South Pacific off Peru
3. NODC Reference No. R391901
4. J. Van Leer (RSMAS), C. N. K. Mooers (U Del.), Grant: NSF/OCE75–22444
5. **Program:** CUEA/JOINT–II MAM 77

Physical/Chemical Oceanograpy: STDs–190, cyclosonde–4

1. RV COLUMBUS ISELIN (RSMAS) Cruise CI7702 Leg 2
2. April 4 to 23, 1977, eastern South Pacific off Peru
3. NODC Reference No. R391946
4. A. J. Huyer (OSU), Grant: NSF/OCE76–00594
5. **Program:** CUEA/JOINT–II MAM 77

Physical/Chemical Oceanography: STDs–162; ocean stations–82; oxygen–15; phosphates, nitrates, nitrites, silicates–82 each
Biology: Primary productivity–38, phytoplankton pigments–80.

1. RV COLUMBUS ISELIN (RSMAS) Cruise CI7702 Leg 3
2. April 29 to May 7, 1977, eastern South Pacific off Peru
3. NODC Reference No. R391948
4. K. L. Smith (SIO), Grant: NSF/OCE76–10535
5. **Program:** CUEA/JOINT–II MAM 77

Chemical Oceanography: Oxygen, phosphates, nitrates, nitrites, ammonia–9 each

Biology: Zoobenthos–4, ATP–ADP–AMP–3, grabs–4
Geology/Geophysics: Cores–9, sediment traps–4.

1. RV COLUMBUS ISELIN (RSMAS) Cruise CI7702 Leg 4
2. May 10 to 20, 1977, eastern South Pacific off Peru
3. NODC Reference No. R391947
4. R. L. Smith (OSU) Grant: NSF/OCE76–00594
5. **Program:** CUEA/JOINT–II MAM 77

Dynamics: Current meters–1 deployed and 60 meters (12 stations) recovered, wind recorders–8
Physical/Chemical Oceanography: STDs–21

1. RV EASTWARD (DUML) Cruise E–5I–76
2. September 29 to October 4, 1976, eastern South Pacific off Peru
3. NODC Reference No. R391973
4. R. L. Smith (OSU), Grant: NSF/OCE76–00594
5. **Program:** CUEA/JOINT–II JASON 76

Dynamics: Current meters–1 station for 70 days
Physical/Chemical Oceanography: Ocean stations–17

1. RV MELVILLE (SIO) Cruise JOINT–II MAM 77 Leg 1
2. March 3 to 9, 1977, eastern South Pacific off Peru
3. NODC Reference No. R391827
4. R. L. Smith (OSU), D. Halpern (PMEL), Grant: NSF/OCE76–00594
5. **Program:** CUEA/JOINT–II MAM 77

Dynamics: Current meters–6 deployed, and 150 recovered, wind recorder–5
Physical/Chemical Oceanography: STDs–24; ocean stations–14; oxygen–9; phosphates, nitrates, nitrites, silicates–14 each

1. RV MELVILLE (SIO) Cruise JOINT–II MAM 77 Leg 2
2. March 12 to 30, 1977, eastern South Pacific off Peru
3. NODC Reference No. R391828
4. R. L. Smith (OSU), A. J. Huyer (OSU) Grant: NSF/OCE76–00594
5. **Program:** CUEA/JOINT–II MAM 77

Dynamics: Current meters–7 deployed, wind recorders–3
Physical/Chemical Oceanography: STDs-141; ocean stations–52; oxygen, phosphates, nitrates, nitrites, silicates–52 each
Geology/Geophysics: Bathymetry–500 nmi

1. RV MELVILLE (SIO) Cruise F DRAKE 77 Leg 4D
2. May 4 to 27, 1977, eastern South Pacific off Peru
3. NODC Reference No. R392283
4. L. A. Codispoti (U Wash.), Grant: NSF/OCE76–04825 A01
5. **Program:** CUEA/JOINT–II MAM 77

Physical/Chemical Oceanography: STDs–110; ocean stations–147; optics–147; oxygen–104; phosphates, nitrates, nitrites, silicates, chlorinity, ammonia–147 each, isotopes–2, dissolved gas (N^{20})–2
Biology: Phytoplankton pigments–147, phytoplankton–147, ATP–ADP–AMP–10

1. RV WECOMA (OSU) Cruise WELOC–77 III Leg 1
2. March 10 to 30, 1977, eastern South Pacific off Peru
3. NODC Reference No. R392012
4. R. C. Dugdale (Bigelow Lab.) NSF/OCE76–00136, J. MacIsaac (Bigelow Lab.) NSF/OCE75–23718, R. T. Barber (DUML) NSF/OCE75–23722, NSF/OCE76–01309, J. Goering (U Alaska) NSF/OCE76–00593 A01, D. Stuart (FSU) NSF/OCE76–82831
5. **Program:** CUEA/JOINT–II MAM 77

Physical/Chemical Oceanography: Ocean stations–38; transparency–40; oxygen–33; phosphates, nitrates, nitrites, silicates, ammonia–40 each
Biology: Primary productivity–19, phytoplankton pigments–40, POC–19, PON–19, phytoplankton–40, DMA–RNA concentrations–40, N uptake/Si uptake–19

1. RV WECOMA (OSU) Cruise WELOC–77 Leg 4
2. March 31 to April 23, 1977, eastern South Pacific off Peru
3. NODC Reference No. R392129
4. J. Goering (U Alaska), R. T. Barber (DUML) Grants: NSF/OCE76–00593 A01, NSF/OCE72–06422
5. **Program:** CUEA/JOINT–II MAM 77

Physical/Chemical Oceanography: Ocean Stations–46; transparency–24; oxygen, phosphates, nitrates, nitrites, silicates–46 each
Biology: Primary productivity–37, phytoplankton pigments–57, PON–24, Phytoplankton–24
Geology/Geophysics: Cores–11

1. RV WECOMA (OSU) Cruise WELOC–77 Leg 5
2. April 24 to May 17, 1977, eastern South Pacific off Peru
3. NODC Reference No. R392245
4. R. T. Barber (DUML), Grant: NSF/OCE76–01309.
5. **Program:** CUEA/JOINT–11 MAM 77

Dynamics: Drogues–3
Physical/Chemical Oceanography: Ocean Stations–35; transparency–17; optics–17; continuous temperatures–5 maps; discrete temperatures and salinities–35; oxygen, phosphates, nitrates, nitrites, silicates, ammonia–88 each; trace elements–15; radioactivity–53; isotopes–53
Biology: Primary productivity, POC, phytoplankton–53 each; phytoplankton pigments–88; microorganisms–35

1. RV WECOMA (OSU) Cruise W7707B
2. July 31 to August 2, 1977, eastern North Pacific off Oregon
3. NODC Reference No. R392137
4. R. L. Smith (OSU), A. J. Huyer (OSU), Grant: NSF/OCE77–07932
5. **Program:** CUEA/Poleward Undercurrent

Dynamics: Current meters–4.
Physical/Chemical Oceanography: CTDs–23.

1. RV WECOMA (OSU) Cruise W7710B
2. October 16 to 28, 1977, eastern North Pacific off Oregon
3. NODC Reference No. R392290
4. A. J. Huyer (OSU), Grant: NSF/OCE77–07932
5. **Program:** CUEA/Poleward Undercurrent.

Physical/Chemical Oceanography: CTDs–18

1. RV WECOMA (OSU) Cruise W7710D
2. October 26 to 29, 1977, eastern North Pacific off Oregon
3. NODC Reference No. R392327
4. A. J. Huyer (OSU), R. L. Smith (OSU), Grant: NSF/OCE77–07932
5. **Program:** CUEA/Poleward Undercurrent

Physical/Chemical Oceanography: CTDs–11, oxygen–110

1. RV WECOMA (OSU) Cruise W7711BB
2. November 16 to 17, 1977
3. NODC Reference No. R392395
4. R. L. Smith (OSU), A. J. Huyer (OSU), Grant: NSF/OCE76–07932
5. **Program:** CUEA/Poleward Undercurrent

Dynamics: Current meters–1 for 7 days

1. RV WECOMA (OSU) Cruise W7711B
2. November 30 to December 2, 1977, eastern North Pacific off Oregon
3. NODC Reference No. R392405
4. A. J. Huyer (OSU), Grant: NSF/OCE77–07932
5. **Program:** CUEA/Poleward Undercurrent

Physical/ Chemical Oceanography: CTDs–10, ocean stations–2, oxygen–90, salinities–20.

1. RV WECOMA Cruise W7712A
2. December 14–16, 1977, eastern North Pacific off Oregon
3. NODC Reference No. R392406
4. A. J. Huyer (OSU), Grant: NSF/OCE77–07932
5. **Program:** CUEA/Poleward Undercurrent

Physical/Chemical Oceanography: CTDs–6, ocean stations-1.

1. RV WECOMA (OSU) Cruise W7801A
2. January 23–26, 1978, Eastern North Pacific off Oregon
3. NODC Reference No. R392464
4. R. L. Smith (OSU), A. J. Huyer (OSU), Grant: NSF/OCE77–07932
5. **Program:** CUEA/Poleward Undercurrent

Dynamics: Current meters–3 for 1,365 days

1. RV WECOMA (OSU) Cruise W7802A
2. February 9 to 11, 1978, eastern North Pacific off Oregon
3. NODC Reference No. R392462
4. R. L. Smith (OSU), A. J. Huyer (OSU), Grant: NSF/OCE77–07932
5. **Program:** CUEA/Poleward Undercurrent

Physical/Chemical Oceanography: CTDs–13, oxygen–80, hydrogen–24.

Appendix B—IDOE Films

The NSF IDOE Section has prepared several films to illustrate phenomena of the ocean environment and the work of IDOE-funded scientists. These 16-mm, sound and color motion pictures are available from the organizations indicated. Abbreviations used are **F** for free loan, **R** for rental fee, and **P** for purchase.

Alpha Cine Labs
1001 Lenora Street
Seattle, WA 98121

Well of Life (27 minutes)–The twin dramas of the ocean's life cycles and the scientific probing of its mysteries are combined in this story of ocean upwelling. Coastal upwelling is the still little-understood process by which the ocean continuously renews its resources, through the motions of wind, water, and the Earth itself. The **Well of Life** deals with that mystery, and the efforts of scientists to uncover its driving forces and learn how it influences and is influenced by weather, climate, and the seemingly limitless round of ocean-linked phenomena. The setting is off the Oregon coast. But the truths presented about balance in the world's ecosystems and the relevance of one field of science to another have universal applications. (English, French, German, Spanish, and Russian versions.) **P**

Centre Films, Inc.
1103 N. El Centro Ave.
Hollywood, CA 90038

The Turbulent Ocean (60 minutes)–A documentary film about the planning and execution of one of the largest deep-sea expeditions in twentieth century oceanographic research. Over 75 scientists and technicians from 18 national and international universities and oceanographic institutions set forth in a coordinated, cooperative effort to find and measure strange and not yet understood motion beneath the surface of the sea called an eddy. **R** or **P**

Cineffects Color Laboratory
115 West 45th Street
New York, NY 10036

The Alchemist Sea (5 minutes)–For nearly 200 million years, the Earth's surface has broken up into massive plates that shift and move–often beneath the sea floor. Scientists, collecting core samples from the sea floor, are discovering there's a relationship between plate motion and the distribution of ore deposits. Their research can help guide our search for metals on the sea floor as well as on continents. **P**

Changing Climes (5 minutes)–Are the unusual weather patterns and severe crop losses of recent years just a passing phenomenon? Or is the Earth sliding into a downward side of a long-term temperature cycle. Scientists are detecting evidence of such long-term cycles and are raising some early warnings. **P**

Where is the Weather Born? (5 minutes)–Weather and climate, it has been said, began in the oceans. A group of scientists have been studying the northern Pacific in the effort to identify the oceanic processes relating to weather conditions over the continents. NORPAX, the North Pacific Experiment, is an effort to understand the interrelationships, for instance, between sea-surface temperatures and long-term weather (or short-term climate). This research could lead not only to understanding, but to prediction. **P**

Living Resources Program
International Decade of
Ocean Exploration Section
National Science Foundation
Washington, DC 20550

Through the Eyes of IRIS (25 minutes)–A technical film report describing to potential users a computer-driven shipboard data acquisition system, IRIS (Interactive Realtime Information System), developed for the Living Resources Program under the International Decade of Ocean Exploration.
The film shows how the system was tested during scientific voyages to West Africa and Baja, California. A towed "Batfish", operating at up to 10 knots and at depths from 0 to 100 meters, reads temperature, salinity, and depth electronically, and draws samples at the same time. The IRIS system holds promise for many useful applications not only at sea, but also in Earth and meteorological studies and management programs. **F**

Time Windows (12 minutes)–Using modern data transmission facilities, ocean scientists engaged in the International Decade of Ocean Exploration, are now able to exchange their data, reports, and findings as readily as dialing the telephone or tuning their television sets. Indeed, that's what happens: information stored in computers linked by telephone give oceanographers across the land ready access to each others' findings, which, with the aid of an adapter, are displayed on regular television sets or printed with the aid of a data facsimile machine. **F**

Modern Talking Pictures Service
2323 Hyde Park Road
Hyde Park, NY 11040

Elements of Mystery (25 minutes)–The film monitors the progress of a team of scientists aboard the research ship MELVILLE as they gather data on chemical composition and determine locations of manganese nodules in the Pacific. The joint research effort, with several universities participating, is attempting to increase understanding of how manganese nodules are formed, as well as their economic potential as an international resource. **F**

NOAA Film Library
12227 Wilkins Avenue
Rockville, MD 20852

Boundary of Creation (27 minutes)–This film describes the efforts of U.S. and French scientists in Project FAMOUS to understand the ever-changing geology of our Earth, particularly the midocean ridges off the Azores. The picture features the probes of the submersible ALVIN in the ocean depths and also portrays research in Hawaii and Iceland. **F**

RHR Filmedia, Inc.
1212 Avenue of the Americas
New York, NY 10036

Cycle in the Sea (5 minutes)–Thanks to the motions of wind, water, and the Earth itself, life in the oceans continuously renews itself. Here is an important story of the balance in the world's ecosystems and its study off the coast of Oregon. **F**

Desert in the Deep? (5 minutes)–That the ocean floor is no desert is beginning to be realized. But the varieties of life forms, from simple organisms to sharks measuring 4 feet between the eyes, were unsuspected until scientists went to sea with cameras able to explore the very deepest reaches of the ocean. **F**

Pastures of the Sea (5 minutes)–Food chains in the sea like food chains on land depend on plants to use the Sun's energy to convert chemical nutrients into food. To understand, and perhaps better use, the resources of the sea, we have to understand its interlocking life cycles. Science is looking at the beginning of the sea's food chain; this film looks at the science. **F**

Rivers of the Sea (27 minutes)–A sea-going expedition leaves Tahiti to gain a better understanding of the oceans and their chemistry–knowledge that is vital in preventing ocean pollution, improving commercial fishing, and understanding climatic conditions. It joins scientists working at sea and in land-based laboratories in California, New York, and Miami. **F**

Science and the Salmon Fishery (5 minutes)–Commercial fishermen have learned by guess and by gosh where to catch fish, but they do not often know why the fish are where they are. A scientific experiment off the Oregon coast is turning up explanations and, with the cooperation of the coho salmon fishermen, is developing a system of fishery predictions that seems to be paying off. **F**

Test Tubes in the Sea (5 minutes)–Can our oceans continue to absorb the urban wastes, oils, and chemicals we discharge into them—or is there a point of no return? An international team of scientists and engineers is trying to find out by measuring pollutants in the sea. Their efforts are giving us a major tool that will help us understand how these contaminants affect the ocean food chain and an indication of how far we can go in continuing to pollute the sea. **F**

Appendix C—Reports and Workshops Sponsored by IDOE

The Caribbean: Geology, Geophysics and Resources. A report on the IDOE workshop on Geology and Geophysics of the Caribbean Region and its Resources held in Kingston, Jamaica, 1975. The report, edited by John Weaver, University of Puerto Rico, includes a geologic-tectonic map compiled by J. E. Case and T. L. Holcombe, which extends from 54° E to 93° E and from 5° N to 24° N. Individual articles include: Geologic Framework of the Caribbean Region (J. E. Case), Bathymetry and Sediments (T. L. Holcombe), Seismicity (J. F. Tomblin), Mineral Resources (P. W. Guild and D. P. Cox). Copies can be obtained by writing: 1) Dr. John D. Weaver, Institute of Caribbean Science, University of Puerto Rico, Mayaguez, P.R.; or 2) Seabed Assessment Program, IDOE, NSF, 1800 G Street NW., Washington, DC 20550.

The Continuing Quest (large-scale ocean science for the future). Report of a study conducted under the auspices of the Ocean Sciences Board of the National Research Council. August 1978, National Academy of Sciences.

Federal Agency Support For Marine-Related Social Science Research. A Report Prepared by the ad hoc Subcommittee for the Interagency Committee on Marine Science and Engineering, December 1976.

Geology, Geophysics and Resources of the Caribbean. Report of the IDOE Workshop on Geology and Marine Geophysics of the Caribbean Region and its Resources, Kingston, Jamaica, 1975.

Minerals from Mantle to Mine, a 7-page article reprinted from MOSAIC May/June 1977, describes the Seabed Assessment Program's Studies in East Asia Tectonics and Resources (SEATAR) project. Copies available free from the NSF/IDOE Office.

Ocean Research in the 1980's. Recommendations from a series of workshops on promising opportunities in large-scale oceanographic research. August 1977, Center for Ocean Management Studies, University of Rhode Island, Kingston, R.I.

Report of the Workshop on Biological Oceanography for Post 1980 IDOE Planning. Center for Ocean Management Studies, University of Rhode Island, April 20-22, 1977.

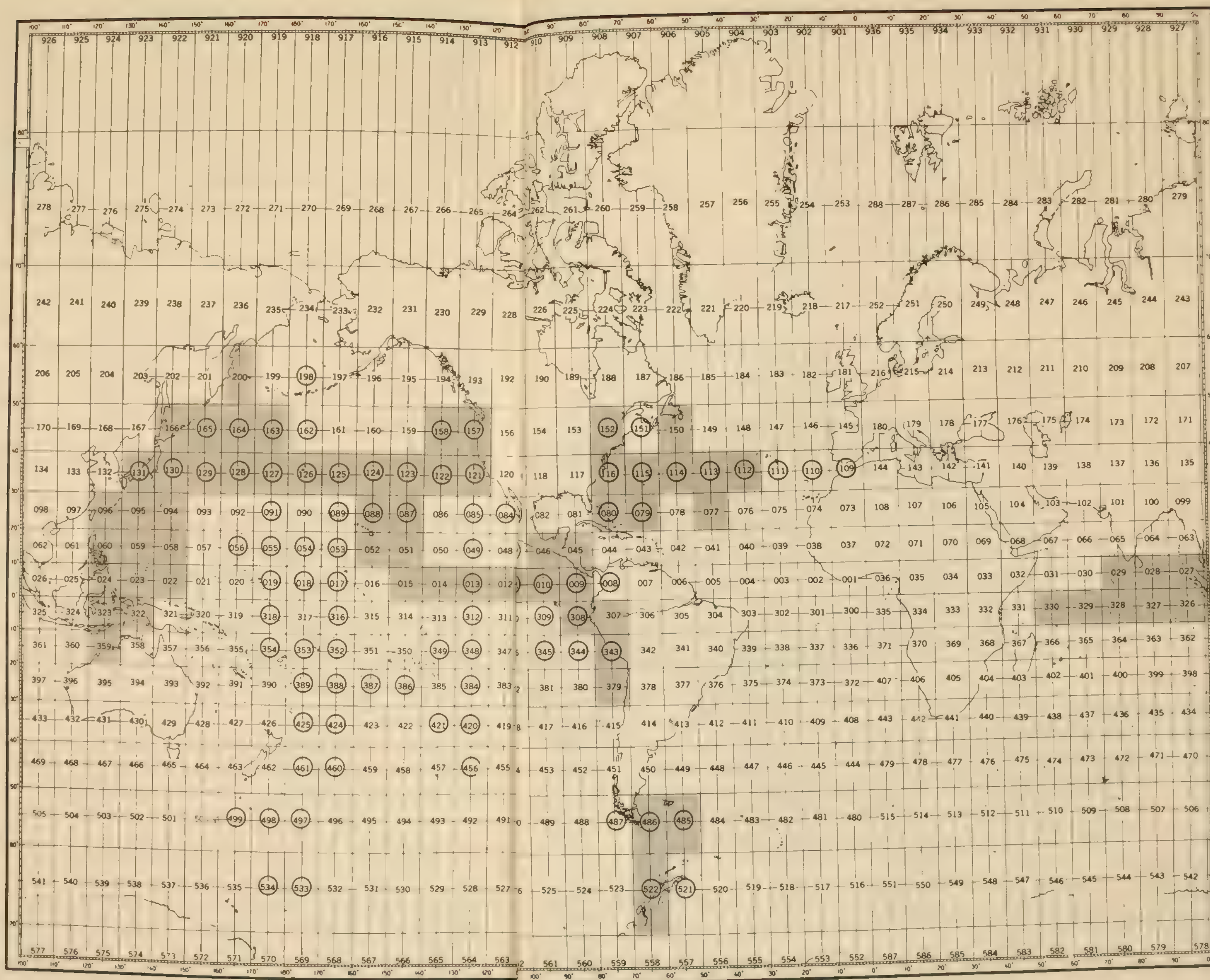
Report of the Workshop on Chemical Oceanography for Post 1980 IDOE Planning. Center for Ocean Management Studies, University of Rhode Island, June 1-3, 1977.

Report of the Workshop on Geochemical and Geophysical Oceanography for Post 1980 IDOE Planning. Center for Ocean Management Studies, University of Rhode Island, June 15-17, 1977.

Report of the Workshop on Physical Oceanography for Post 1980 IDOE Planning. Center for Ocean Management Studies, University of Rhode Island, March 21-23, 1977.

Shelf Sediment Dynamics. A national overview (June 1977) report of a workshop held in Vail, Colorado, November 2-6, 1976.

Transient Tracers in the Ocean. A Report to the International Decade of Ocean Exploration, National Science Foundation, of a Design Workshop held at Lamont-Doherty Geological Observatory, February 10-12, 1977.



IDOE material received:
■ROSCOP Forms
○Data

Chart of 10° by 10° geographic areas (Marsden Squares) within which were collected data and information reported in this publication and received by NOAA's Environmental Data and Information Service during the period April 1977 to April 1978. Note: Data and ROSCOP forms are seldom received at the same time.

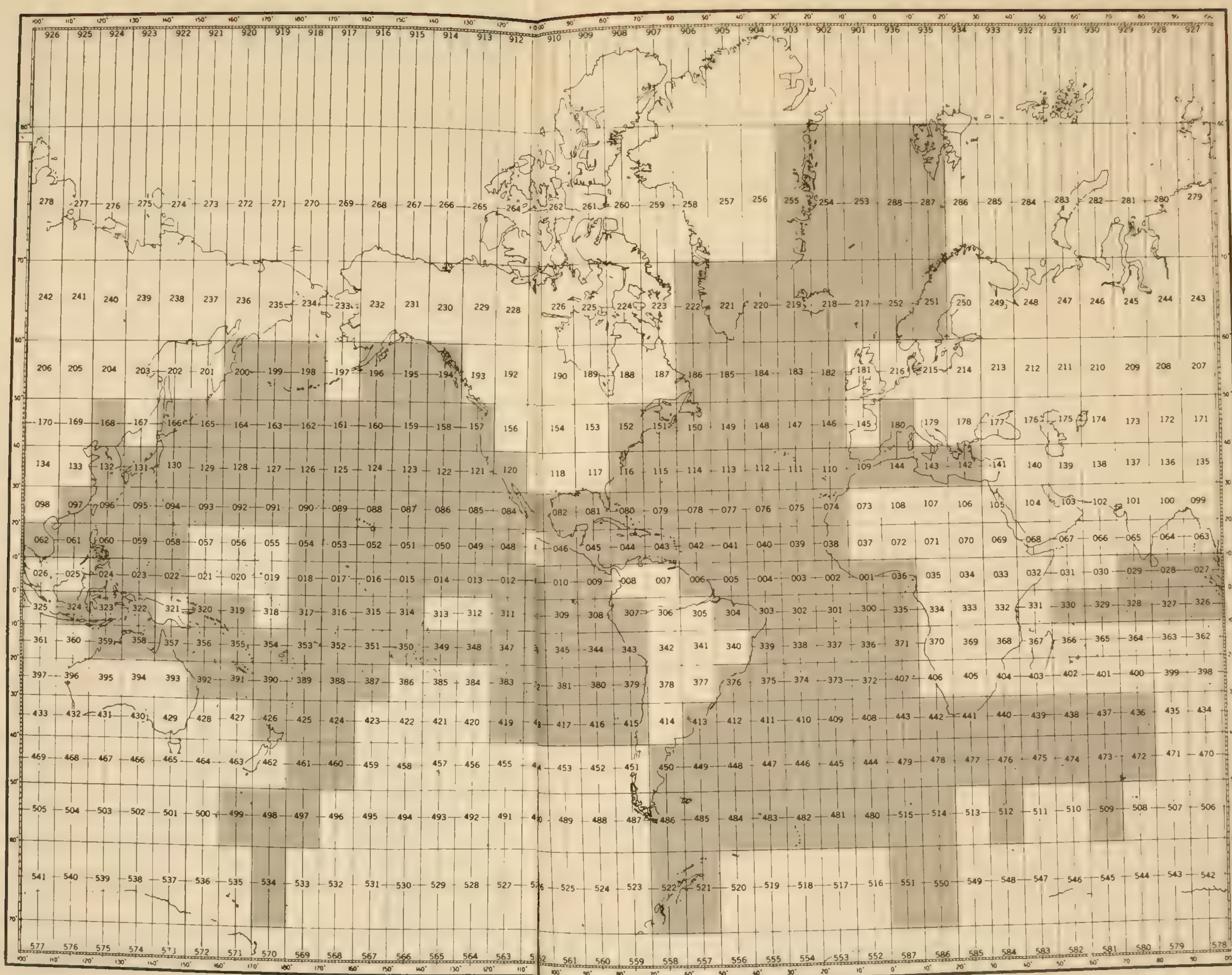


Chart of 10° by 10° geographic areas (Marsden Squares) within which were collected data received by NOAA's Environmental Data and Information Service during the period January 1970–April 1978 (shaded squares) resulting from IDOE-sponsored research.

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Environmental Data and Information Service
Washington, D.C. 20235

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